REPRO-MASTER

TR 56-67-12 (U

STUDY OF FLIGHT MANAGEMENT REQUIREMENTS DURING SST LOW VISIBILITY APPROACH AND LANDING OPERATIONS

VOLUME I

DEFINITION OF BASELINE SST LANDING SYSTEM

October 1967

Prepared by:

Richard E. Shoemaker
Walter B. Gartner
William J. Ereneta
Vincent R. Donohue

NASA TECHNICAL EDITOR

Charles C. Kubokawa

Prepared under Contract No. NAS2-4406 by

SERENDIPITY ASSOCIATES
Los Altos, California

For:

Ames Research Center
National Aeronautics and Space Administration

TR 56-67-12 (U)

STUDY OF FLIGHT MANAGEMENT REQUIREMENTS DURING SST LOW VISIBILITY APPROACH AND LANDING OPERATIONS

VOLUME I:

DEFINITION OF BASELINE SST LANDING SYSTEM

October 1967

Prepared by:

Richard E. Shoemaker
Walter B. Gartner
William J. Ereneta
Vincent R. Donohue

NASA TECHNICAL EDITOR

Charles C. Kubokawa

Prepared under Contract No. NAS2-4406 by

SERENDIPITY ASSOCIATES

Los Altos, California

For:

Ames Research Center

National Aeronautics and Space Administration

CONTENTS

Page

FIGURES

TABLES

ABSTRACT

This is the first of several reports designed to support NASA Ames Research Center SST crew factors simulation studies. The present focus is upon flight management functions during approach and landing. This report establishes the context and defines the baseline low visibility landing system anticipated for the United States' SST. The baseline system assumes an ILS type signal source on the ground and redundant automatic control systems in the aircraft. Runway imaging systems and heads up displays were not included.

Flight management functions are defined and broken down into special types. Requirements for flight management, and support provided to the crew, are described along with equipment activities in a narrative operational sequence description.

SUMMARY

The present report is divided into three sections. The first section describes the operational context, the operational functions required during approach and landing and components of the SST baseline landing system which is to perform those functions.

Section 2 derives Flight Management (FM) requirements by first distinguishing the characteristics of FM functions and then examining their embodiment in approach and landing operations and their relationship with other operations control functions. That section divides FM requirements into six subsets and locates specific FM functions within the four approach and landing phase segments.

The last section attempts to examine FM functions which are performed by the aircrew within the context established by the baseline landing system presented in Section 1. Particular attention is given to provisions of the baseline landing system for support of FM functions. The purpose of this section is two-fold: it will establish the preliminary data base for evaluating specific FM tasks; and since it includes crew participation in other operations control functions, it should serve as a contextual framework for subsequent simulation efforts.

This report is primarily concerned, then, with establishing a frame of reference for the analysis of FM requirements during approach and landing operations aboard the SST recognizing that the projected configuration of means by which the operations are completed directly affects the character of FM tasks. The utility of this report relative to subsequent efforts is to delineate what is provided by the equipment to support FM functions performed by the crew and the relationship to other operations control functions.

INTRODUCTION

NASA research efforts in support of the national supersonic commercial air transport program have been directed toward a number of critical development areas. One of these areas is the nature and kind of crew tasks performed in a supersonic transport and particularly the study of crew workload and subsystem and/or flight deck design requirements.

As a direct outgrowth of studies by Serendipity Associates and others related to SST crew performance, certain kinds of crew tasks may be identified as being crucial to the safe and economical utilization of the SST. Increasing demands on previously effective human performance dictate increasing applications of mechanical and/or electronic devices to replace or augment man's performance capabilities. Questions regarding the necessary and desirable extent of such applications have always represented lively issues and it is now fashionable to search for "optimal integrations" of man and machine capabilities. Considerable effort has been applied to accomplishing this objective and for certain perceptual and psychomotor tasks, such efforts have often been successful. However, in more and more system contexts, excessive demands are increasingly being referred to more exclusively cognitive tasks, often characterized as involving "judgment" or "decision making", and while there is no shortage of attempts to replace or support human performance in this sort of task, successes have not been notable.

In the context of potential crew roles in supersonic transport operations, a subset of system functions generally referred to as "Flight Management" can be defined, emphasizing such responsibilities as assessing the overall flight situation, judging the significance of particular events, and exercising final authority with respect to how the system is operated, i.e., what actions are taken and when. This type of task is characterized by a man-machine interaction that is primarily cognitive in nature. That is, the relationship of the crew to the flight instruments, displays, system and subsystem displays, and visual environmental reference, is one of information gathering and integration and decision making, rather than one of direct control interaction. In some cases this type of task is a relatively simple one; for example, the flight engineer may monitor a set of subsystem displays in order to detect possible malfunction indications. His response in terms of direct control of any aircraft component is limited to that elicited by a malfunction indication, or various remedial control actions he may make in order to prevent malfunction.

At its most complex, that task may be typified by the kind of crew behavior seen during the approach and landing phase of a flight. In this case, the pilot and copilot are required to scan a wide variety of displays, make judgments based on the information gathered from these displays, and respond with indirect or direct control actions. It is this type of cognitive crew task toward which this study is directed.

Study Objective

The principal objective of the current study is to provide data which can be applied by the Ames Research Center in the investigation of SST crew factors problems via simulation. The scope is limited to an investigation of flight management functions performed during SST approach and landing. In accomplishing the general objective a number of intermediate objectives must be obtained:

a. Define the SST landing system and distinguish flight management functions;

b. Analyze flight management tasks and describe potential problems in obtaining and/or supporting crew performance; and

c. Determine feasible research objectives within the context of simulation capability at Ames Research Center and recommend research design specifications and criterion measures for problem(s) selected for simulation investigation.

In the course of the planned research, these objectives will be obtained and results presented in three separate reports.

Study Reports

The purpose of this, the first report, is to define the baseline or "working" SST landing system and to outline the crew's role in flight management activities. The SST all weather landing system, or a reasonable approximation based upon proposals, state-of-the-art advances, FAA requirements and pilot's and airlines position papers, is presented in this report along with the manner in which its displays and controls would or could be used to support the crew in performing flight management functions.

The adequacy of support provided for flight management will be assessed in the next phase of the study and presented in the second interim report. This assessment will be based upon an empirically derived model of information processing by airline captains and a detailed analysis of data availability and accessability provided by the baseline landing system described in the current report. Potential problems related to the performance of flight management and pilot acceptance will be delineated along with solution concepts when possible.

The last major technical report will specify simulation requirements for investigation of flight management functions selected from the set of potential problem areas listed in the second report. Criteria for selection will include a consideration of existent and projected simulation capabilities at Ames Research Center. Implementaton of simulation design recommendations may serve to verify existence of a critical flight management problem or to test a particular solution concept.

SECTION 1

AN OVERVIEW OF THE SST LANDING SYSTEM CONCEPT

The purpose of this section is to establish the context within which both the supersonic transport and its crew must perform. In this report we are concerned primarily with the approach and landing phase of SST operations and will restrict our discussion to factors which are believed to influence those operations.

Beginning with the outside environment, this section describes the conditions under which the SST landing system would be operationally employed. Landing system functions are introduced followed by a discussion of general landing system components. The section is concluded with the tabular presentation of specific components and capabilities presumed for the airborne portion of the SST landing system.

Air Traffic

While SST traffic will be relatively light in the 1970's, total air traffic will be heavy. An FAA spokesman estimates future air traffic as shown in Table 1 (ref. 1). Presumably, the SST will be required to take its place in the approach queue, preceded and followed by other aircraft spaced in time and distance. Current spacing on the ILS glide slope is about three minutes between aircraft. Time separation will probably be reduced at major airports in 1970.

Weather

Two variables are used to classify weather conditions which affect landing operations. The FAA and other international aviation

Table 1. Forecast of Aviation Activities.

	FY 1966	FY 1975
Active Airmen	over 500,000	850,000
Registered Aircraft	95,442 Gen. Avn.	170,000 Gen. Avn.
Civil	2,125 Air Cr.	2,500 Air Cr.
	97,567	172,500
Fl. Hours Gen. Aviation	16.7 Million	30 Million
Flight Services	29.1 Million	over 50 Million
IFR Tfc. Handled (ARTCC)	13.5 Million	23.1 Million
Total Terminal Operations	41.7 Million	70 - 75 Million
Number of Passengers	113.9 Million	250 - 275 Million
Passenger Miles	76.4 Billion	187 - 207 Billion
Freight Ton-Miles	1.7 Billion	5 - 10 Billion

organizations have defined three categories of landing conditions based upon: (1) Runway Visual Range (RVR) and (2) decision height. Both measures reflect visibility conditions. RVR is measured on the ground and is an expression of how far one can see when looking down the runway. Decision height is defined as the altitude at which the pilot of an aircraft must execute a "missed approach" if he has not made sufficient visual contact with the landing surface to enable manual control of the landing operation.

The FAA has not yet defined performance and safety certification requirements for Category III weather minimum conditions, but Table 2 below summarizes the FAA Low Minimum categories.

Table 2. Weather Minima for Landing Operations (ft).

	Decision Height	RVR
Category I	200	2600
Category II	100	1200
Category IIIa	None	700
Category IIIb	None	150
Category IIIc	None	0

Landing System Functions

The term all weather landing system is potentially misleading because it suggests that the aircraft could land under such extreme conditions as 60 mph gusts or on a flooded or ice-covered runway. A more appropriate and specific descriptor might be a low visibility landing system (LVLS), as we have arbitrarily chosen to refer to it in this report.

The configuration of means by which a landing is performed during poor visibility conditions has not been completely defined for the United States' SST. It is not possible, therefore, to examine the system for the SST, but rather, we shall define a baseline system which reflects the most prevalent forecasts of what the ultimate SST LVLS will be.

The information necessary to safely perform the approach and landing maneuver is theoretically the same under VFR and IFR conditions. The means by which the data is obtained is often drastically different. In the most general sense, the landing system (which may include a pilot) is concerned with the controlled two dimensional closure of the aircraft with a particular point on the ground, i.e., the runway. Information as to the spacial relationship of the aircraft with an optimum landing point is translated into appropriate aircraft control actions to effect a safe landing. While airspeed was ignored in the general statement of the landing maneuver, certainly a safe landing depends upon its proper control.

Landing systems, in general then, perform certain functions which serve to deliver the aircraft safely from a point in the air to one on the ground. Under VFR (Visual Flight Rules) the landing system consists basically of a pilot, the flight control system, and the pilot's perception of the landing area. IFR (Instrument Flight Rules) conditions require the same set of functions but differ in the means by which they are accomplished.

The general set of functions by which the approach and landing operations are completed were delineated in a previous report (ref. 2) and serve as a framework for the operational sequence description in

Appendix A. As originally derived, the operations described were those performed by the landing system per se, and were not allocated to crew or equipment.

Landing System Components

Low visibility automatically controlled approach and landings are technically feasible and Category II landing systems are state-of-the-art (ref. 3). Many authorities believe that in the near future all weather landings will be as much a part of day-to-day flying as autopilot operation during cruise is now. However, the particular route to Category IIIc landings is quite controversial. The reported antagonism between British and American concepts for a poor visibility landing system revolves around the proposed role of the pilot. The American position (voiced by the FAA and most pilots and airline representatives) stresses the need for the pilot to stay in-the-loop. In practice, the difference seems to be whether backup is provided by another automatic system or the pilot-in-command. From the point of technology little difference between concepts is noticeable. That is, most technical effort is being placed upon deriving better and more reliable information to execute the landing whether fed to a pilot, autopilot, or both.

The principal components of a modern instrument landing system are:

- Ground based navigation and guidance equipment
- Ground based Air Traffic Control (ATC) facilities
- Airborne navigation and guidance equipment
- Flight control system and flight deck materials (maps, charts, terminal plates, etc.)

The first three components are concerned with accomplishing the functions which under VFR were handled by the pilot's visual contact with the landing area, i.e., acquisition or derivation of guidance information. The fourth item includes the crew and an Automatic Flight Control System (AFCS).

Ground Based Navigation and Guidance

Instrument Landing Systems (ILS) are deployed at nearly all major airports throughout the world. This system or an improved version will most likely constitute the ground based component of the SST LVLS. The ground components of the ILS generate radio signals which when received and interpreted by the airborne components define the optimum flight path for landing.

The worldwide deployment of ILS plus the fact that it has been used with success in Category I operations and is in current use for Category II landings where certifications requirements are met, are good indications that this or a similar system will provide guidance information to the SST landing under Category II or possibly Category III conditions.

Because of inaccuracies in vertical guidance information at less than 100 feet, it is questionable whether the current version will be satisfactory for Category III. Airborne Instruments Laboratory is developing a new system which they call the AILS (Advanced Integrated Landing System). AILS is reportedly unaffected by difficult terrain and provides the pilot with azimuth, glide slope, and distance-to-go information while at the same time elevation and azimuth are displayed to an operator on the ground.

The ILS glide slope projection angle is normally adjusted to 2.5 to 3 degrees above horizontal so that it intersects the middle marker at about 200 feet and the outer marker at about 1,400 feet above runway elevation. Special terrain noise conditions at a given airport will determine the specific glide slope projection angle. ILS approaches into Saigon and Da Nang, Vietnam are conducted along a 4.5 degree slope to reduce the possibility of being hit by sniper ground fire. Elsewhere, around the world the glide slope angle varies between 2.5 and 3 degrees.

U. S. Category A approach and runway lighting is assumed for the present study, i.e., high intensity runway edge lighting, centerline lights, touchdown zone lights, and sequenced flasher or strobe approach lighting. It should be noted, however, that standardization of airport lighting cannot yet be assumed, particularly when international airports are considered. Runway markings and terrain features in the immediate runway surrounds will provide additional visual cues during daylight operations. Conventional all weather runway marking is assumed, including distance markers in the first 2,000 feet of the landing runway. No other specific provisions for indicating runway remaining or "distance-to-go" is expected to be available. It appears that while present requirements are satisfactory for Category II conditions, intensities of approach and runway lights would have to be increased for lower visibilities.

Precision Approach Radar (PAR) is currently installed at some airports. It is distinguished from general surveillance radar by the fact that it includes altitude information and is oriented with respect to a specific runway. Commercial air transports rarely request PAR approaches today and though ILS approaches are monitored by PAR only an extreme deviation from the glide slope path will elicit a communication from the PAR operator.

At present, GCA or PAR is used primarily by military aircraft. It would probably be used for SST approaches only in the event of ILS failure coupled with a critical fuel situation or similar diversion deterrent.

Ground Based Air Traffic Control (ATC) Facilities

Based on the FAA's Design for the National Airspace Utilization System we can anticipate a generally more flexible airway structure in the 1970's. While Air Traffic Control (ATC) functions and components will remain much the same, considerable automation is expected. In a recent address, an FAA representative made the following projection:

> The biggest change affecting flight operations in the 1970's will be the tremendous growth in air traffic. The air traffic control (ATC) system will remain familiar, but technically and procedurally improved in its ground navigation facilities; pilot/controller communications; and radar service -- with marked emphasis on beacon altitude readout. A nationwide ATC computer network is scheduled to process flight data on controlled aircraft. . . . . Airspace structuring will undergo evolutionary changes to provide more area positive control service per traffic demands. Integrating significant numbers of STOL/VTOL/SST aircraft is going to further complicate air traffic growth. Terminal area congestion will continue and alleviation means close collaboration of all aviation elements. (Ref. 1)

Ground based elements which accomplish the ATC functions are listed below:

Enroute ATC:

Air Route Traffic Control Centers (ARTCC)

Terminal Area Control (TAC)

Approach Control Center and Tower or

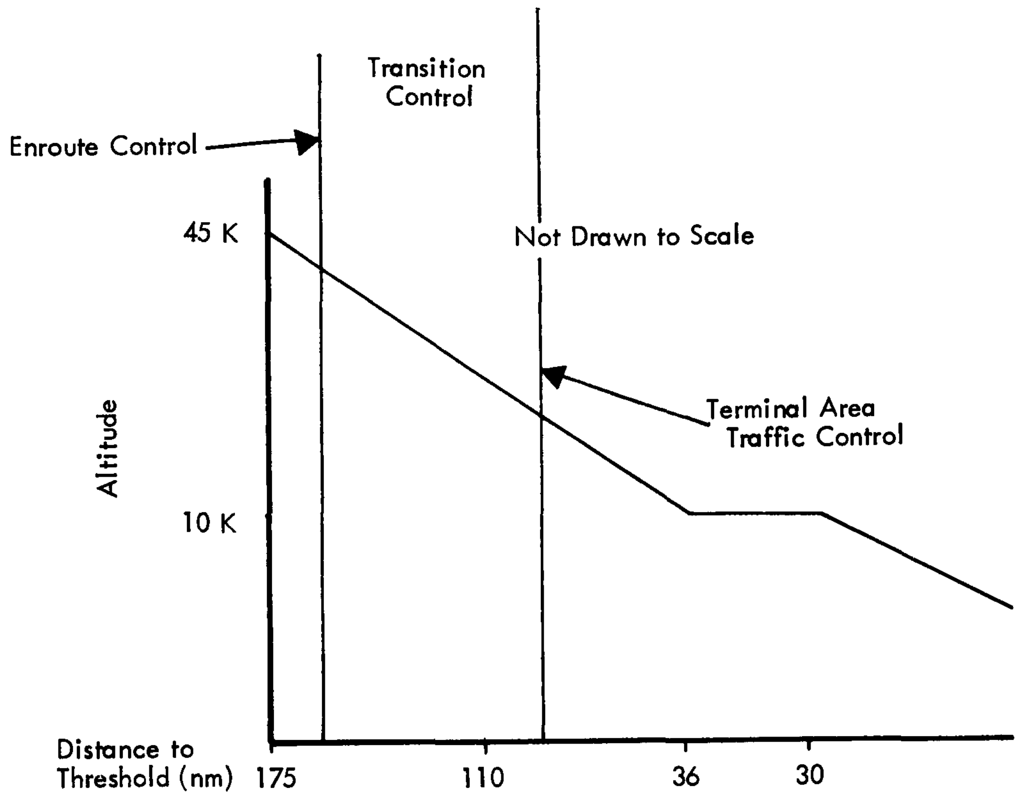
Radar ATCC

As shown in Figure 1, ground control is transferred from ARTCC to TAC when the aircraft is approximately 150 miles from the intended landing site. In the projected airspace utilization plan commercial aircraft operating above 40, 000 feet are under radar surveillance and control throughout their flight, thus enabling closer separation with increased safety. When the SST descends below 40, 000 feet in preparation for landing, it will probably still follow jet airways, though radar vectors may be provided in the terminal area.

General Description of the SST Approach and Landing

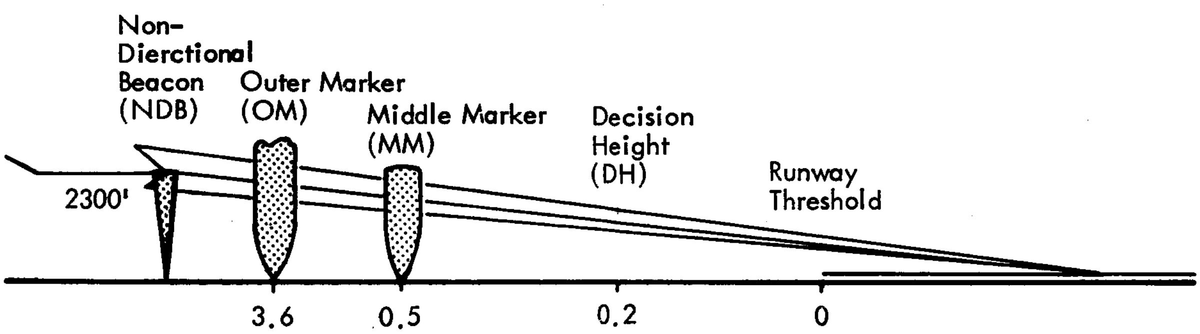
A brief description of the SST approach and landing operations as viewed from the airborne portion of the landing system will serve to illustrate its operation and will form a general structure around which the specifics of the operational environment can be organized. Rather than attempt a general description of a "typical" approach and landing it was believed that a specific approach to an existant airport would be more directly useful. We selected Dulles International because it will undoubtedly be an SST Terminal and because equipment capable of simulating an approach and landing to Dulles is currently under construction at Ames Research Center.

Descent from a cruise altitude of about 70, 000 feet begins approximately 200 miles from the destination terminal area. The aircraft becomes subsonic at about 45 K feet and the wings are then swept at 42 degrees aft, which is reportedly optimum for subsonic flight. If a landing is possible at the intended destination (RVR $\gtrsim$700 feet for Category IIIa) the aircraft will continue descent while bleeding off airspeed. At about 150 miles out, the SST will be down to $\approx$40 K feet, flying at Mach 0. 9. Ground control will be transferred to a transition control center which will direct the flight into the terminal area. The terminal entry point is usually defined by a VOR station approximately



Altitude (above sea level)	45 K	30 K	10 K
Relative Altitude (above runway)			
Distance to Threshold	175 nm	110 nm	36-30 nm
Time to Threshold	30 min	22 min	12-11 min
Equivalent Airspeed (EAS-knots) - Normal landing	516	470	360-300
Wings Sweep	42°	42°	30°
Outboard Flaps	Faired	Faired	
Inboard Flaps	0°	0°	
Outboard Slats	0°/6°	6°	
Inboard Slats	0°/25°	25°	
Nose	down	down	down
Landing Gear	up	up	up
Rate of Descent	2000 ft/min	2000 ft/min	0
Pitch Attitude (Body)			
Time to Touchdown (Main Gear)			
Remarks	Mach 0.9 descend to 30 K		Decelerate to 300 kts EAS and descend to 2300 ft

Not Drawn to Scale



NDB	MM	DH	Threshold	Touchdown
2300 ft	462 ft	413 ft	363 ft	313 ft
1987 ft	149 ft	100 ft	50 ft	0
10-7.3 nm	0.5 nm	0.2 nm	0	1500 ft
4-3 min	14 sec	10 sec	0	
160	127	127	127	127
20°	20°	20°	20°	20°
30°/50°	30°/50°	30°/50°	30°/50°	30°/50°
21°/40°/60°	21°/40°/60°	21°/40°/60°	21°/40°/60°	21°/40°/60°
30°/55°	30°/55°	30°/55°	30°/55°	30°/55°
35°	35°	35°	35°	35°
down	down	down	down	down
down	down	down	down	down
0	574 ft/min	574 ft/min	168 ft/min	0
	4.9°	4.9°		7.3°
	18 sec	14 sec	4 sec	0
Decelerate and Intercept Glide Slope	Descend on Glide Slope	Descend on Glide Slope	Flare	

Figure 1. Theoretical SST Approach Profile to Dulles International Airport

100 miles from the airport. About this time ground control is transferred to the Terminal Area Traffic Control Center and the SST is vectored to intercept the approach localizer beam or directed to hold. For a landing at Dulles International Airport, the SST, wings now swept to 30 degrees aft, would establish its initial approach at 1,600 feet and begin descent upon arrival over the outer marker. The aircraft will intercept the glide slope about four miles from the runway threshold. Airspeed continues to bleed off as the aircraft proceeds down the glide slope. If we can generalize from conventional commercial jets, EAS will be 1.3_{V_S} + 10 kts. Prior to reaching the decision height, the pilot decides to continue the landing or execute a missed approach (for Category II or better). The flare maneuver for the Boeing SST will be performed at about 70 feet. Sink rate should then be about 2.8 feet per second and the airspeed about 132 knots.

SST operating costs are estimated to be between $2,000 and $3,000 per hour as compared to $1,200 per hour for subsonic jet air transports. The official position seems to be that the SST will not receive preferential treatment in the landing pattern. That was also the position when jet airliners were introduced but the practice of refeeding them into the pattern rather than to the end of the line after a missed approach might constitute special treatment. Nonetheless, a missed approach or being forced to hold for a period of time could seriously affect an airline's profit margin.

Baseline Low Visibility Landing System Description

As stated in the introduction to this section, it is necessary to describe a LVLS for the SST which will pose problems similar to those faced by SST designers and users. It would be a simpler task to simply choose a complete system off the shelf but that doesn't appear likely for the actual SST LVLS.

The baseline system described in this report is a composite which seems to reflect the thinking of those who will influence the ultimate selection for the SST. The principal components of the LVLS were previously discussed and are briefly sketched in Figure 2 below. The

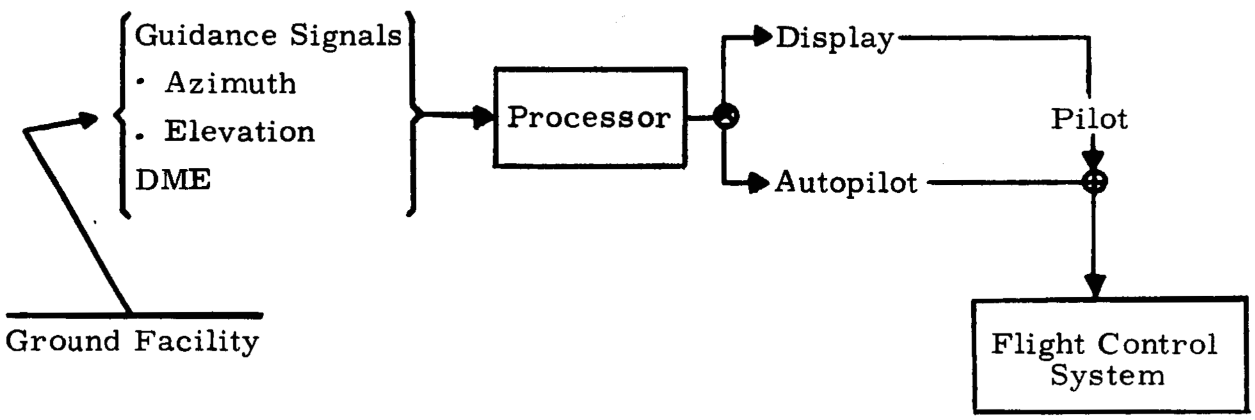


Figure 2. Generalized sketch of Instrument Landing System.

focus of the present study is on the flight management functions performed during SST approach and landing. Our concern is therefore with the airborne system components.

The airborne components of the LVLS basically consists of:

1. A Localizer Receiver

2. A Glide Slope Receiver

3. A Localizer-Glide Slope Deviation Display and

   a. Localizer Coupler
   b. Glide Slope Coupler
   c. Autopilot

4. Pilot

5. Flight Controls

6. Flight Deck Materials

The glide path information is usually displayed on a vertical situation indicator, flight director or Attitude Director Indicator (ADI). Localizer deviation is displayed on a Horizontal Situation Indicator (HSI). An uncoupled (manual) approach requires that the pilot control the aircraft so as to null the localizer/glide slope deviation signals on the display. With the ILS signals coupled to the autopilot, the autopilot flies the approach. For increased reliability additional ILS receivers and autopilots are often used as well as self test and self monitoring features.

Initial development of the baseline system for this report was by necessity largely eclectic, being based upon various sources of varying reliability and authority. As data was obtained relative to what was planned or proposed for the Boeing SST, itself, it seemed more useful to follow their projections whenever possible. Of course, Boeing Corporation is also anticipating the desires of the airlines and the constraints of the FAA. The SST (including the landing system) specifications described by Boeing in their Phase III proposal "reflects extensive coordination with United States and non-United States airlines and the FAA" (ref. 4).

In consideration of the state-of-the-art in landing systems it is also possible to estimate what the capabilities of an SST system could be. Anticipating the outcome of the process of converting constraints, reliability demands, preferences and state-of-the-art into hardware is somewhat tenuous but it is necessary to assume some realistic configuration if we are to define potential performance problems.

The system, as described, should not be viewed as the one which will be aboard the B-2707. It is still a composite, though emphasizing available SST proposal data and recent efforts in the area of all weather landing systems.

A graphic description of the baseline LVLS is given in Figure 3. Minor differences between that and Boeing's proposal for the SST are discussed in the Equipment/Capability list in Table 3. That table sets forth the system components which are defined herein as comprising the SST LVLS. A brief description of component features or capability sets the framework for crew performance requirements presented later. The LVLS described in the table is not exhaustive in terms of all required components nor completely definitive in terms of system operation. What has been included is a brief description of those components and their operation which are believed to have a potential bearing on the performance of flight management.

It should be re-emphasized here that the components which make up the baseline SST LVLS represent the state of our knowledge at this point in time. Subsequent analyses will also consider revisions as they are introduced during the period of this research. A number of developmental systems, such as the Advanced Instrument Landing System (AILS) and "self-contained" systems employing airborne infrared sensor techniques, were examined in the present sutdy but considered inappropriate for inclusion in the baseline LVLS concept. Emphasis was placed on defining a system with minimum Category IIIa capability as the initial reference for study. Concepts and techniques under consideration in developmental systems could then be examined as possible solutions to flight management problem areas disclosed in the present study.

While Table 3 lists the equipment and capabilities chosen to represent the baseline SST LVLS, then, it does not show the capabilities which were not included. Had we done so the list could get as large as we cared to define the inclusion criteria. Certain omissions, however, deserve mention and specific justification. The Head Up Display (HUD), for example, is often suggested as a visual aid in low visibility approaches.

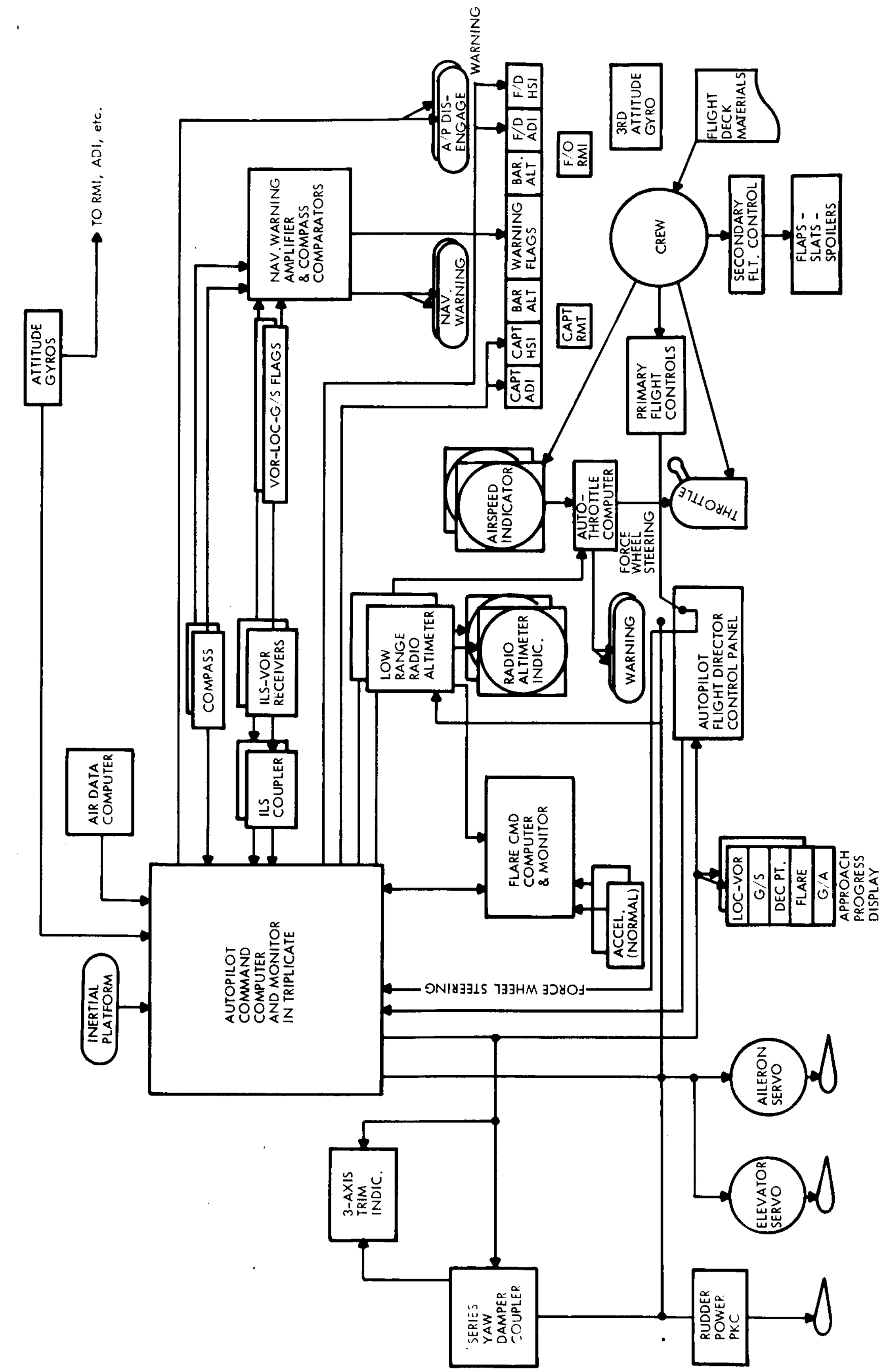


Figure 3. Baseline SST LVSS and Associated Equipment.

Table 3. Baseline SST LVLS Components.

Equipment	Features/Capabilities
1. Automatic Flight Control System	
a. Autopilot	1. Three channels -- operating in parallel for pitch and roll
	2. Self monitoring -- direct comparison of tune signals
	3. Split axis control -- controls roll and/or pitch
	4. Fail passive -- autopilot automatically disengages and returns controls to position prior to failure
	5. Force wheel steering -- autopilot accepts inputs by the pilot through control wheel and rudders
	6. Go-around pitch control -- establishes optimum pitch when go-around maneuver is selected
b. ILS Approach Coupler	1. Localizer/glide slope couple -- converts ILS into commands to autopilot
	2. Selected axis -- can be engaged on localizer, glide slope or both
c. Autothrottle	1. Manual airspeed selection -- throttles automatically adjust to hold selected airspeed
	2. Airspeed hold or Mach hold will hold the aircraft to the airspeed or Mach number existing at time of engagement
	3. Throttles automatically retard during final landing maneuver

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
d. Electronic Command System	1. Force applied to flight control is converted into electronic signals which actuate mechanisms which in turn move control surfaces
e. Stability Augmentation System	1. Automatically engaged in all axes when main electrical busses are energized, the stability augmentation system operates in series with the pilot's control to improve handling quality. It has limited authority in roll, pitch and yaw axes
2. Airborne Navigation and Guidance System	
a. Integrated Flight Director -- Attitude Indicator	1. Pitch and roll attitude
	2. Pitch command
	3. Roll command
	4. Inclinometer (Ball)
	5. Rate of turn (Needle)
	6. Glide slope deviation
	7. Localizer deviation
	8. Expanded localizer deviation
	9. Airspeed command
	10. Minimum decision altitude
	11. Go-around indicator
	12. Radio altitude above runway
	13. Runway alignment

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
b. Horizontal Situation Indicator (HSI)	1. Magnetic heading 2. Selected heading 3. Selected course 4. Course deviation including localizer deviation 5. Bearing indicator a. VOR -- LOC b. ADF c. LORAN (optional) 6. Glide slope deviation 7. DME
c. Radio Magnetic Indicators (RMI)	1. A separate RMI is provided for the pilot and one for the 1st officer 2. The RMI displays a. Magnetic heading b. Bearing derived from ADF No. 1 or VOR No. 1 c. Bearing derived from ADF No. 2 or VOR No. 2
d. Radio Altitude - Vertical Speed Indicators	1. Radio altitude 2. Selected minimum altitude (alarm sounds at selected altitude) 3. Vertical speed 4. Vertical speed command

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
e. Pressure Altitude Indicator	1. Pressure altitude
	2. Selected barometric pressure correction
f. Airspeed Indicator	1. Calibrated -- indicated airspeed
	2. Calibrated airspeed command
	3. Maximum operating speed
	4. Mach number
	5. Air temperature (static, total and non-standard day difference)
	6. Overspeed alarm
g. True Airspeed Indicator	1. True airspeed derived from one of two air data computers
3. Computers	
a. Two Air Data Computers	1. Provides data inputs to:
	a. Air data displays
	b. Autopilot/flight director computers
	c. Autothrust computers
	d. Inertial navigation systems
	e. Propulsion instrumentation
	f. Flight recorder
	g. Angle of attack and warning control system
	h. ATC transponders (altitude reporting)
	i. Hydraulic fluid/air cooling control
	j. AIDS (provisions)

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
b. Three Autopilot/Flight Director Computers	1. Provide roll and pitch channel command instructions for manual and automatic flight
c. Two Autothrust Computers	1. Compute thrust requirements and provide control signals to autothrust mechanism
d. Flare Computer	1. Shown in Figure 3, as separate, it may be incorporated into autopilot/flight director computer as might GO-AROUND logic 2. Computes control requirements for autoflare maneuver
4. Flight Mode Selector Panel (Located directly above pilot's center panel) (See Figure 4)	1. Selections made on this panel control autopilot, autothrottle and flight director 2. Manual mode options: with the manual mode selected on the flight mode selector panel, inputs are controlled by the pilot using the manual control panel located below the main panel 3. Manually controllable parameters are: a. Pitch Axis (1) Vertical speed rate ($\pm$8, 000 feet) (2) Altitude hold (range 0 - 80, 000 feet) b. Roll Axis (1) Roll attitude/heading hold - command input via the turn knob turn the aircraft and hold the new heading as the wings become level (2) Heading select -- autopilot will capture and hold a manually selected heading

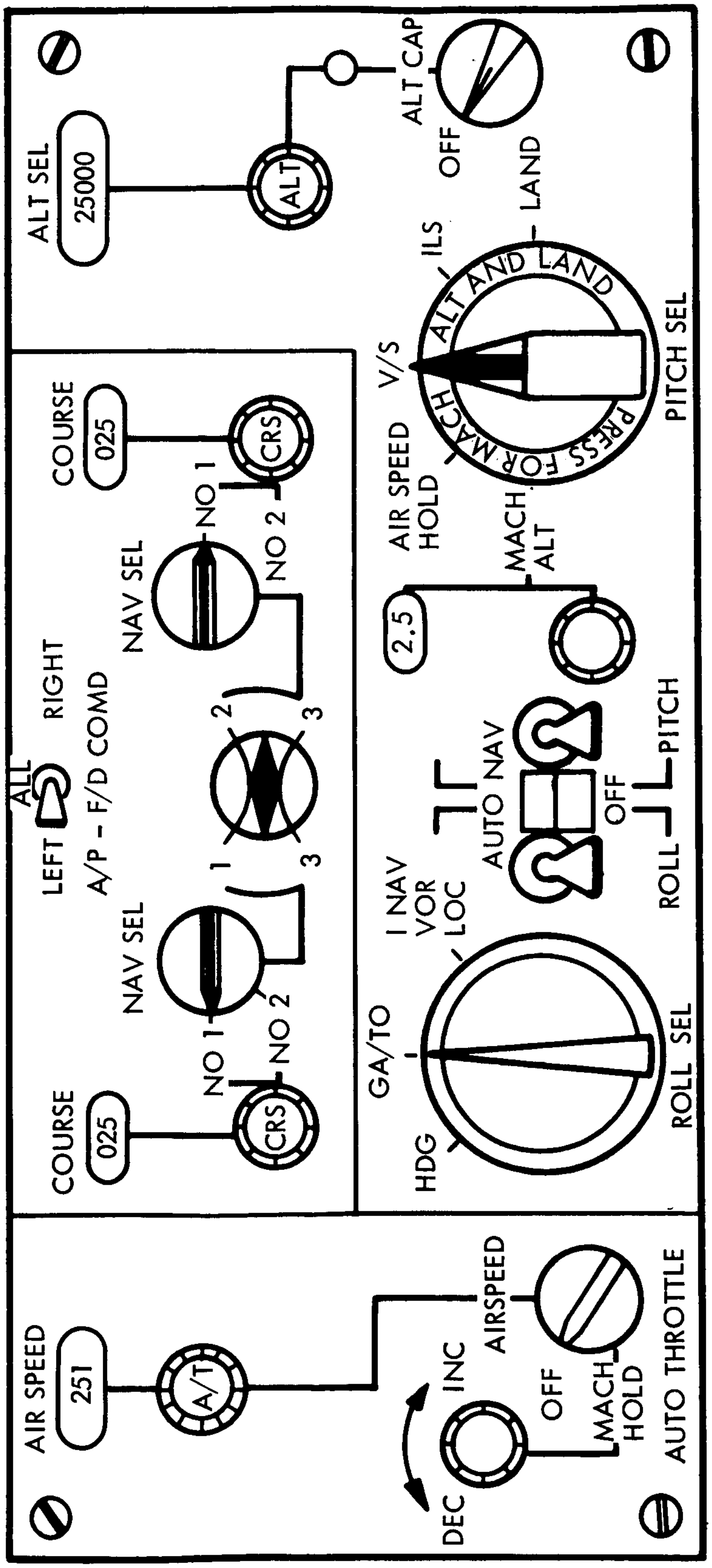


Figure 4. Flight Mode Selector Panel (Sketched as per Boeing Phase III SST Proposal - not to scale)

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
	4. Auto-navigation modes a. Pitch Axis (1) Vertical speed and altitude hold range same as manual (2) Airspeed hold (3) Mach-altitude (sonic boom/overpressure Δp) (4) Altitude capture -- range of 1,000 to 30,000 feet (5) Glide slope -- auto-capture above or below beam (6) Stabilization for altitude above airport of 1,000 feet to 3,000 feet, ground speed of 160 knots or less (7) Land -- controls sink rate to 2.8 ± 1 fps at touchdown. Automatically engaged at 50 - 100 ± 2 feet of altitude with glide slope engaged (8) Go-around/takeoff (actuated by the heel of the pilot's throttle hand and is independent of normal auto-pilot functions) b. Roll Axis (1) Go-around/takeoff (2) Heading selection (3) Inertial navigation (4) Localizer (a) Capture up to $\pm 90^{\circ}$ of intercept angle (b) Track command limits of $\pm 30^{\circ}$ at capture, attenuated to $\pm 5^{\circ}$ at flare (5) VOR -- airplane can decouple from VOR radial over station, select new radial and fly out on selected course

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
	5. Flight director display commands -- commands for auto-pilot and flight director are similar. Flight director does not display manual modes
5. System Monitoring and Failure Warning Equipment	
a. Approach Progess Display	1. Approach progress displayed via annunciator located over each flight director display 2. When auto-land mode is selected separate annunciators indicate: a. VOR/LOC, armed (amber) and capture (green) b. GS (glide slope) armed (amber) and capture (green) c. MDA (minimum decision altitude) illuminates blue when selected altitude is reached (as measured by the radio altimeter) d. Flare, armed (amber) and initiation (green) e. GA (go-around) illuminates amber when armed -- goes green if pilot selects GA.
b. System Status and Warning Indicators	1. Automatic components readiness a. The auto-land system is tested and displays readiness in two ways: (1) Enroute test Manually selected while enroute, this test checks the auto-land circuitry and illuminates the flare annunciator green to indicate readiness

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
	(2) Automatic test Once the glide slope is captured an automatic check of the system is initiated and the flare annunciator illuminates amber upon successful completion when the aircraft reaches 500 feet 2. Instrument failure warnings -- displayed via flags in the window of affected instruments 3. Comparator warning indicator -- illuminates when a significant discrepancy exists between pilot and copilot instrument(s) 4. Master warning -- located above the ADI, it flashes when instrument flags are displayed, when a system's warning light is illuminated on the engineer's panel and when a light on the master warning panel is illuminated 5. Master warning panel -- failure of pilot's or copilot's flight instruments illuminates appropriate light on the panel a. Approach gate b. Barometer altimeter c. Radio altimeter d. Heading e. Attitude f. CMD (Command) g. Glide slope h. LOC (Localizer) and master warning light 6. Aural takeoff and landing warning device -- indicates improper gear, flaps, slats and/or wing configuration

Table 3. Baseline SST LVLS Components (Continued)

Equipment	Features/Capabilities
	7. Fire and overheat warning
	8. Engine fire warning -- warning bell and master fire light as well as lights indicating specific fire area and illumination of the handle of the appropriate fire switch
	9. Autopilot disengage light -- illuminates when the autopilot is disengaged due to malfunction or exceeded limits
	10. Autothrottle disengage -- illuminates when autothrottle is disengaged due to malfunction or exceeded limits
	11. BITE (Built In Test Equipment) results -- probably displayed on engineer's instrument panel
6. Angle of Attack Warning and Control System	1. Warns of approach to stall by shaking control wheel and executes auto-pitch down if stall is imminent
7. Communications Equipment	
a. Dual Localizer Receivers	
b. Dual Glide Slope Receivers	
c. Dual VOR/TACAN Receivers	
d. ADF Receiver	
e. VHF/UHF Transceivers	
f. Radar Transponders Identity and Altitude Code	
g. Marker Beacon Receivers	

Table 3. Baseline SST LVLS Components (Concluded)

Equipment	Features/Capabilities
8. Flight Crew	
a. Pilot	
b. Pilot/Navigator	
c. Pilot/Engineer	
9. Miscellaneous	
a. Rain Removal System	
b. Collision Avoidance System (some type will probably be included)	

The Head Up Display was originally developed to increase the precision of VFR landings, but many who have flown a HUD under low visibility conditions have become advocates of the concept for use in Category II and III landing systems. The argument for the HUD assumes that it is possible to see something of the ground area and that information so gained will be useful to the pilot. The first assumption holds for visibility perhaps as low as 700 feet RVR. Airline pilots state that you can always see something; which brings us to the second point of the assumption. Is the information gained in a visual contact a few seconds before touchdown useful?

A Category IIIc landing system theoretically has no need for a HUD. In fact, some of our British colleagues believe that pilot takeover at the heights at which visual contact might be made under Category III could only degrade the landing maneuver.

We have not included a HUD in our baseline SST LVLS. While the open aviation literature indicates that airline pilots in general favor the HUD concept it is also noted that they tend to reject specific implementations.

In their review of all weather landing systems, Sperry (ref. 3) lists six reasons why the HUD has not gained more favor with aircraft operators:

1. System cost (approximately $100, 000 typical)
2. Optical problems
3. System reliability
4. Pilot acceptance
5. Dependence on additional (or improved) ground navigation aids
6. Cockpit installation problems

Another rather conclusive factor which led to the exclusion of the HUD in the baseline LVLS is that none appears planned for the SST, neither Boeing 2707 nor the Concorde.

Other means for enabling the pilot to look out the windscreen while monitoring flight instruments are also being developed. Peripheral vision flight directors, electrocular displays and uncollimated windscreen displays are all under development and refinement. Present indications are that no such devices will be provided on the SST flight deck.

Still another approach to the problem of low visibility landings is the use of CRT pictorial displays. These usually try to represent the essential features of the terminal area in an attempt to approximate the VFR perceptual environment. Such displays vary from austere points of light which outline the runway to multicolored highways and speed markers. Mention should also be made of exploratory work at the Boeing Company with a television camera mounted under the aircraft fuselage and behind the main landing gear. Much more visual information would be available to the pilot if access to this viewing position could be provided via TV monitors on the flight deck and successful landings have been accomplished by reference to such displays.

Approach and landing systems which use a contact analog display are sometimes criticized for their use of the ILS signals which tend to be inaccurate at low altitudes. Runway imaging systems like beacon vision and microvision do not rely on ground based equipment except for radar transponders or reflectors. They are primarily airborne systems, but typically require a large electromagnetic sensor and relatively large display apparatus which tends to detract from their otherwise promising character.

No evidence has been seen that suggests Boeing or the airlines is planning a contact analog or other CRT director displays. The Boeing SST prototype does have a CRT which is used for ground mapping and for anticipating weather conditions in the flight path. However, the present location of the display on the instrument panel does not encourage its use as a flight director display. In consonance with the "minimum capability" concept adopted for defining the baseline system, neither symbolic CRT displays nor direct TV viewing systems have been included in the LVLS.

SECTION 2

GENERAL FLIGHT MANAGEMENT REQUIREMENTS

The primary focus of the present study, as indicated in the introduction, is on a subset of SST flight operations control requirements characterized as "flight management" functions. In this section, the distinguishing characteristics of flight management functions are set forth and then applied to identify specific requirements for flight management during SST approach and landing operations. A brief conceptual analysis of flight management is presented first in order to introduce and clarify the terminology adopted for subsequent study efforts and to develop a working definition of flight management activities.

It will be seen that flight management functions are closely inter-related with other operations control functions, such as flight control, navigation, and aircraft subsystem control, which are the more direct means of achieving SST flight objectives during the approach and landing. An overview of these control functions will thus be necessary to the more specific identification of flight management requirements and will be given next. With this framework established, a comprehensive delineation of the flight management requirements which may be expected to emerge during routine SST approach and landing operations is presented. In this section, emphasis is placed on how these requirements develop within the assumed operational context and on the general character of the assessment and/or decision problems involved. It is important to note that specific means for accomplishing flight management objectives are not considered in this discussion. The intent is to identify the requirements that any configuration of means (i. e., crew members, aircraft instrumentation and associated sensor and computing equipment, fixed operating procedures, etc.) should be able to satisfy. Implementation concepts for flight management functions, derived from the baseline SST landing system design concepts are presented in Section 3.

Defining characteristics of flight management functions in the present study, the term "Flight Management" (FM) is used to distinguish a class or kind of function and not as a label for a particular function which will subsequently be defined. As a kind of function, FM is initially understood as one of five classes of functions which, taken as a set, cover all of the operations control functions performed in the aircraft during flight to achieve SST operational employment objectives. These operations control functions were distinguished in a previous NASA report (ref. 2) as:

1. Flight Control
2. Navigation
3. Flight Management
4. Subsystem Control
5. Communications

The term "function" as used here, refers to a performance requirement, i.e., a specified change in the state of a designated object, process, system, etc., which must be defined without any mention of the means employed to effect the change. This state-change may be either a physical or non-physical event; there are, in principle, no constraints on how it is specified. The term "flight management" can thus be used to label or characterize a set of functions, but these functions are not considered to be <u>defined</u> until an object is designated and a desired or required state-change is specified.

The general character of FM functions and their relationship to other operations control functions is schematized in Figure 5. Note especially that operations control objectives are most directly achieved through the performance of flight control and, to a lesser extent, subsystem control. Note also that FM functions are "additive", i.e., operations control objectives could be achieved in their absence. The rationale for including FM functions is to increase the probability of achieving specified objectives and/or of satisfying specified constraints as regards safety, reliability, efficiency, passenger comfort, economy, etc. The general character of FM functions is further indicated in this schematic in that they are concerned with generating "commands and/or control instructions", which can be applied to adjust or direct the implementation of the other operations control functions, and that these outputs are derived from ongoing flight situation data as well as data reflecting aircraft and subsystem states.

It can now be seen that the "object" or process affected by FM functions is the SST inflight operations control system itself, i.e., the configuration of means for implementing flight control, navigation, subsystem control, and, perhaps, communications functions. State-changes in the object system which are subsequently used to define particular FM functions are expressed in terms of "input" information states, representing actual and/or assigned "values" for aircraft and subsystem states, flight situation parameters, etc., and of "output" information states, representing control actions required, if any, to direct and/or adjust these "values" in accordance with FM operating criteria. By definition, then, FM covers all requirements for assessing or diagnosing flight situations, aircraft performance, subsystem operation, and conditions in the flight environment and for formulating and resolving action decision problems which may arise out of these assessments. These requirements may be satisfied by "fully automated" equipment systems or by unaided crew members -- but under more realistic system mechanization concepts they are likely to require a more or less complex

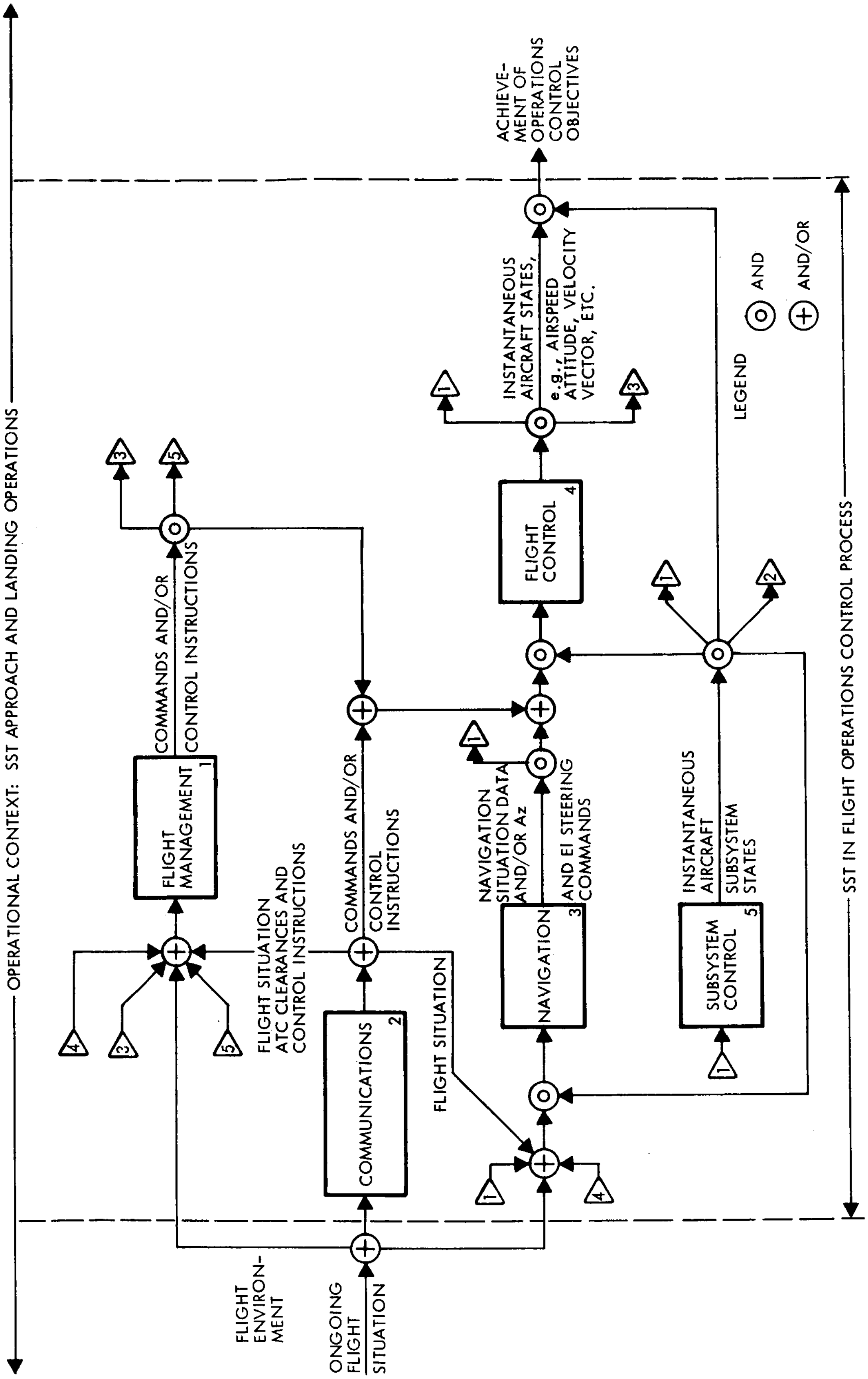


Figure 5. General Character of FM Functions as they Relate to Other Operations Control Functions

integration of crew members (especially the pilot-in-command) and equipment (e.g., built-in system performance monitoring equipment and warning systems).

In this study, the position is taken that responsibility for FM cannot be realistically assigned to equipment, on the general grounds of crew accountability for the consequences of flight control activities.

This issue is discussed more fully in Section 3 where selected means of implementing FM functions are identified. It is noted here to point up the general character of FM functions as crew information processing activities. As such, FM is viewed as consisting of three types of crew behavior. First is the detection of operationally significant conditions and events which results from monitoring the ongoing flight situation. In most instances a diagnosis or assessment of these conditions and events will be necessary in order to determine their character and/or to determine whether they are in or out of tolerance with regard to FM objectives and acceptance criteria. This diagnostic or evaluative activity is the second component of FM. Finally, decisions may be required relative to the adequacy of ongoing flight control, subsystem control, or navigation activities. Action decisions, then, are the third basic component of FM and these decisions are taken to resolve any uncertainties regarding the operation of the aircraft which may arise out of ongoing assessment of the flight situation.

As an illustration, consider four basic assessment and/or diagnostic functions which may be construed as key components of FM:

1. Assess/diagnose aircraft performance
2. Assess/diagnose flight progress
3. Assess/diagnose operational conditions
4. Assess/diagnose aircraft subsystem operation

As indicated in Figure 5, aircraft performance is most directly a function of flight control and is expressed in terms of instantaneous values on selected aircraft state parameters, e.g., airspeed, altitude, velocity vector, attitutde, etc. In general, FM requirements of the first basic type can be distinguished by: (1) identifying (selecting) the parameters of interest (e.g., those being controlled during a given flight phase or phase segment), (2) identifying the required/assigned/ desired parameter values, and (3) considering how these "required values" are established and how information on "actual values" is made available for FM in a given system.

For example, suppose that "cross-track error" is selected as a controlled parameter. During an initial approach, with the aircraft approaching the outer marker and stabilized on the localizer, the "required value" for this parameter may be "a one-dot displacement on the localizer deviation indicator" or approximately 500 feet to either side of the assigned localizer course. This control objective can be achieved on the basis of steering commands from the navigation function or derived more directly from navigation situation data and does not necessarily require an input from FM, as indicated in Figure 5.

In this example, the "required value" for cross-track error might be established by programming it into a flight director computer as a basis for generating azimuth steering commands. In this instance no requirement for FM in deriving these required values is yet established. On the other hand, "acceptable" limits on cross-track errors may be established by flight operations policy or pilot judgment and applied to flight control whether azimuth steering commands were available or not. In this case FM requirements can be defined by specifying an information input reflecting actual cross-track position and an output representing a command or control instruction in some form to flight control to bring the actual cross-track position to within FM-derived tolerances.

Considering that information on actual cross-track position might be directly available to the flight manager, no FM functions for deriving the necessary input information on actual values would be required. But, again, if information from, say the navigation function, does not give aircraft cross-track position directly, then a FM function may be required to "estimate" or "infer" cross-track position. Subsequent FM functions would be required to establish and/or apply assessment criteria to such actual aircraft state data and determine appropriate action required, and translate it into a command or control instruction to flight control.

As an additional example, consider the third type of FM function, i.e., assess/diagnose operational conditions. Assume that the aircraft is making an approach under actual Category II weather conditions and the parameter of interest is something like "effective Runway Visual Range" (RVR). In this example the "required value" might be something like ".... the pilot must be able to see, to his satisfaction, his aiming point for landing on the runway from a specified critical decision height, say 100 feet". In this case, FM functions may be required to predict effective runway visual range based on reported ceilings and RVR and/or direct observation of terrain features, approach lights, etc. Requirements for FM functions which derive from the availability and characteristics of information on the actual state of the parameter of interest are exemplified here. In this situation, it should also be clear that a possible defining outcome of a related action decision function would be the generation of a command or control instruction to flight control to initiate a go around maneuver.

The foregoing is intended to be suggestive rather than definitive in that the parameters identified in the examples are not necessarily the ones that will be selected for detailed analysis. The intent here has been to communicate something of the concept of flight management as it is applied to the landing sequence descriptions and landing system mechanization concepts outlined in subsequent sections of this report.

Flight Management Requirements During Routine IFR Approach and Landing

It should be clear from the foregoing discussion that flight management requirements are initially derived from a consideration of the conditions, situations and events which can have a significant effect on the successful execution of the approach and landing sequence. Four categories of operationally significant conditions can be distinguished to identify generic assessment/diagnostic requirements and to establish a basis for deriving additional monitoring and decision making requirements:

1. Flight Progress - the present and projected status of the flight with respect to the flight plan, clearance constraints, ATC control instructions, and flight path control objectives.

2. Aircraft Performance - the behavior of the aircraft with respect to optimum operating practices, maneuvering requirements, and other flight control objectives.

3. Operational Conditions - the present and projected status of conditions in the immediate flight and ground environment, including significant weather phenomena, other air traffic, availability and operating status of navigation and control facilities in the terminal area, terrain features, and airport conditions.

4. Aircraft Subsystem Operation - the on-line configuration and operating status of critical aircraft equipment and systems performing flight control, navigation/guidance, subsystem control, and communications functions.

Assessments and/or diagnoses performed in these four areas generate requirements for two additional FM functions when important uncertainties or action requirements are detected. One is the resolution of flight progress decisions, i.e., flight plan deviation or clearance change decisions, commitments to proceed with designated flight phases or to initiate specific maneuvers, the timing of certain flight control actions, etc. The second is, in general, a response to out-of-tolerance or marginal conditions and to specific system malfunctions and/or emergency situations and entails the selection of non-routine or emergency actions. Both requirements may arise out of assessments or diagnoses in all four areas set forth above, though the first is most directly associated with assessment of flight progress and operational conditions and the second with aircraft subsystem operation and aircraft performance.

With the addition of one more general requirement, that of monitoring and recording critical flight history and subsystem operation parameters in support of broader or long term FM objectives, we can now identify the seven basic FM functions addressed in this report:

1. Assess and/or diagnose flight progress
2. Assess and/or diagnose aircraft performance
3. Assess and/or diagnose operational conditions
4. Assess and/or diagnose aircraft subsystem operation
5. Resolve flight progress decisions
6. Resolve non-routine and/or emergency action decisions
7. Record flight history and subsystem status data

General Character of FM Functions

Following a brief discussion of the general character of the seven basic FM functions, requirements for component FM activities during each phase segment of the SST approach and landing sequence are delineated. In the general characterization of basic FM functions, an attempt is made to identify the principal diagnostic and action decision problems comprising each function in terms of the SST operational context materials presented in Section 1. Delineation of more specific requirements is then presented in tabular form and related to the profile-defining events of the approach and landing sequence.

Assess and/or Diagnose Flight Progress

The progress of a designated SST flight, from the time it arrives at the altitude or position specified by its clearance for initiating a letdown into the terminal area until it is rolling on the runway at its assigned destination airport, is defined by a closely controlled flight path in both vertical and horizontal dimensions and in respect to arrival times at key control points. Strict adherence to track keeping limits, altitude constraints and airspeed restrictions is a routine matter for scheduled air carrier operations throughout the flight profile, but these demands must be met with the highest degree of precision during approach and landing operations. There is an ongoing flight management requirement, then, to carefully follow the actual condition of the flight with respect to such demands and constraints, to stay far enough ahead of what the airplane is doing to anticipate control requirements, and to apply corrective actions, if necessary, soon enough to preclude significant deviations from the assigned approach and/or clearance instructions.

The key inputs to this function during approach and landing are the assigned enroute course to the terminal entry point, the assigned instrument approach plan, initial and amended letdown, approach and landing clearances, special terminal area maneuvering instructions such as radar vectors and holding requests, ETA's and low approach initiation time assignments, and data reflecting present aircraft position, ATA's at control points, velocity vectors, and flight path projections. Component diagnostic activities are primarily concerned with the continuous determination of present aircraft status on such critical flight path control parameters as cross-track error, along-track error, relative height and rate of descent, flight path alignment with the runway, and time of arrival at critical control points. Assessments of present status against clearance instructions, established approach and landing procedures, safety-of-flight and regulatory considerations, etc., are also ongoing.

Assess and/or Diagnose Aircraft Performance

The major emphasis in the performance of this FM function is on ensuring that critical flight maneuvers required during approach and landing are executed in accordance with operating techniques appropriate to the handling qualities and performance characteristics of the SST and with constraints derived from such considerations as situation-specific terrain features or weather phenomena (e.g., wind shear), pilot acceptance of maneuvering demands and aircraft response, economic penalties, noise control in the vicinity of the airport, and passenger comfort. Critical flight maneuvers include vertical flight path control during penetration, localizer capture, glide slope capture and stabilization, the landing maneuver from flare initiation to touchdown, and, when necessary, the go-around maneuver.

Basic flight control parameters such as airspeed, vertical speed, attitude and attitude rates, absolute altitude, and velocity vectors are assessed in this function and, again, considerable importance is attached to "staying ahead of the aircraft", i.e., anticipating tendencies for movement in the direction of out-of-tolerance conditions. In addition, the timing of certain control actions (e.g., flare initiation), the response characteristics of the aircraft, and such intangibles as the "feel" of the instantaneous flight situation are carefully appraised. More specific flight management requirements of this type will be identified with reference to particular maneuvers and/or flight path control objectives rather than isolated aircraft performance parameters.

Assess and/or Diagnose Operational Conditions

For approach and landing operations under Category II conditions, the focus of this FM activity is on the accurate prediction of Runway Visual Range (RVR) at the prescribed decision height and on the severely time-constrained assessment of the adequacy of extra cockpit visual references as the aircraft approaches and attains that point in the landing sequence. There is a concurrent requirement to detect and appraise such other critical conditions as crosswinds, wind shear (velocity gradients), turbulence, and other weather phenomena which may combine to degrade or distort the information available through external visual reference. These assessments are all related to the "see-to-land" requirement inherent in the Category II situation.

Although significant weather phenomena are the principal concerns of this activity, FM attention must also be directed toward other conditions and events in the flight and ground environments which are essential to the safety and success of the approach and landing. These include spatial and kinematic relationships with other air traffic, terrain features and structures (e.g., towers) affecting navigation tolerances, the operating status and characteristics of available ground navigation and guidance facilities, the availability and status of various landing aids at the destination airport, runway conditions, and so on. Component diagnostic and assessment activities might thus be concerned with a wide range of environmental factors and with determining their impact on the ongoing flight situation and the realization of flight control objectives.

Assess and/or Diagnose Aircraft Subsystem Operation

This general FM function covers all requirements during approach and landing for determining the on-line configuration and operating mode of airborne equipment systems and components and for monitoring or assessing their performance. Critical equipment components of the BWLS, such as the flight director system, the automatic flight control system, flight control and navigation instrumentation and computing equipment, are the chief concern of this function, but attention to other aircraft systems (e.g., electrical, fuel, hydraulic, etc.) is an ongoing requirement and must also be considered. In the present study, the examination of this function will focus on subsystem operating states which have a direct effect on the bad weather approach and landing problem. More routine monitoring and assessment of aircraft systems will be considered only where they bear directly on this problem.

Provisions for testing the readiness of landing system components, for detecting and isolating malfunctions, for reconfiguring on-line units to preclude interruptions or degradations in operational capability, for generating warning and advisory signals, and for monitoring the occurrence of critical equipment operating states are all examples of overall system features concerned with this management function. Again, the general requirements are to "stay ahead of the airplane" by detecting trends toward out-of-tolerance equipment operation as soon as possible and to achieve required reliability and "fail safe/fail operational" goals when operating limits are exceeded.

Resolve Flight Progess Decisions

It was pointed out earlier that action decision problems in the operational situation are expected to arise out of the performance of one or more of the foregoing assessment/diagnostic functions. With respect to flight progress, these decisions have to do, generally, with the successive determination of whether or not the flight should proceed with the approach as planned and finally with a commitment to initiate the terminal landing maneuver. Decisions to deviate from the established flight plan, to request clearance changes, to abort the approach, to execute a go-around or missed approach procedure indicate the possible outcome of this management function.

A basic element of the approach adopted in the present study is that the formulation and resolution of such decision problems is a major variable in the implementation of FM functions and that this variable should not be prematurely fixed by the adoption of analytically derived models of operational decision problems. The consideration of crew information processing in the development and resolution of decision problems will be an important part of the analysis of cognitive task loading planned for the next phase of the study, but at this point only a general statement of the kinds of decision problems that may be expected to arise can be given.

Resolve Non-Routine and Emergency Action Decisions

The introductory comments to the preceding function are also applicable here. Decision problems distinguished here have to do with selecting or adopting a particular course of action after it has been determined that a non-routine or emergency condition exists. For the most part, these decision problems will arise out of the assessments or diagnoses of aircraft subsystem operation outlined above. Corrective actions will include decisions to reconfigure on-line systems, modify operating modes, switch-over to backup systems, initiate emergency procedures, request assistance, etc.

It is reasonable to assume that the criticality, safety, and economic considerations associated with decisions of this type will call for a considerable amount of preplanning for such contingencies and for specifying as completely as possible, in advance, the decisions to be taken. In the subsequent analysis of this general FM function, decision problems which can be clearly anticipated and resolved in accordance with well defined rules or operating policy will be screened out where it can be readily determined that no significant crew factor or LVLS design problems are likely to develop. Emphasis will thus be given to the more complex decision problems or those which are difficult to resolve in the time available or with the amount and quality of data which is expected to be available to the system.

Record Flight History and Subsystem Status Data

This general function covers all requirements for recording flight path data, selected aircraft performance and configuration parameters, company and FAA specified flight logs, flight deck voice communications, and any special aircraft subsystem performance (e. g., fuel consumption) or operating status data considered useful for maintenance analysis. These data are recorded primarily for post-flight or accident analyses and are not routinely used for in-flight functions. For this reason and the fact that automatic devices requiring little or no crew participation are used for most of the recording functions, no significant crew factor problems are envisioned for this FM activity. The function was included to assure comprehensiveness and the relationship to other FM functions, such as the ongoing concern for recording fuel "how-goes-it" data and the possible use of subsystem performance data recorded enroute in management problems during approach and landing, will be considered in subsequent analyses. But the function is seen, at this point, as warranting relatively little attention in the present study and no further breakdown of the FM requirement is considered necessary here.

Delineation of Flight Management Requirements

Specific requirements for FM during the four principal segments of the SST approach and landing sequence defined in Section 1 are identified in Table 4. These requirements statements are arranged into six subsets corresponding to the generic FM functions just introduced. In general, these requirement statements should be construed as operational functions which must somehow be performed to assure a successful approach and landing. No specification of the means whereby each of these functions will or might be implemented is given or intended at this point in the analysis. For this reason, the requirements outlined here will serve as points of reference in the next section where assumptions adopted in this study regarding crew participation, equipment utilization, operating procedures, etc., are documented.

Table 4. FM Requirements for Each Phase Segment of the Approach and Landing

Generic FM Function	Requirements During Penetration	Requirements During Initial Approach	Requirements During Final Approach	Requirements During Landing
1. Assess/diagnose Flight Progress	a. Assess assigned course to the terminal entry point (TEP) b. Detect cross-track error conditions c. Assess cross-track errors d. Assess letdown against altitude clearance constraints e. Assess rate of approach to TEP f. Assess time of arrival at TEP	g. Assess assigned course and/or heading to localizer intercept point h. Detect cross-track error conditions i. Assess cross-track errors j. Assess altitude against clearance constraints and establish minima k. Assess localizer intercept point and acquisition vector l. Assess approach to Outer Marker	m. Assess localizer deviation n. Assess glide slope deviation o. Assess flight path alignment with runway as aircraft approaches authorized decision height p. Assess absolute altitude as aircraft approaches authorized decision height	None
2. Assess/diagnose Aircraft Performance	a. Assess maintenance of descent schedule airspeed and rate-of-descent b. Assess thrust required to maintain descent schedule	f. Assess approach to assigned initial approach altitude and timing of level-off maneuver g. Select optimum localizer intercept heading	l. Assess initiation of glide path control and stabilization on glide slope m. Assess localizer and glide slope tracking	u. Assess overall "feel" of aircraft altitude and flight path dynamics for acceptance as initial state for landing maneuver v. Assess initiation of flare maneuver

Generic FM Function	Requirements During Penetration	Requirements During Initial Approach	Requirements During Final Approach	Requirements During Landing
	c. Assess pitch attitude and rate d. Assess airspeed against configuration constraints and terminal area operating limits e. Select optimum initial approach airspeed	h. Assess localizer capture maneuver and stabilization on assigned localizer course i. Assess airspeed control j. Select optimum final approach airspeed k. Assess glide slope capture maneuvers	n. Assess airspeed control o. Assess rate-of-descent p. Assess flight path angle q. Assess pitch attitude and rate r. Assess yaw attitude (crab angle) s. Assess roll attitude and rate t. Assess thrust required for airspeed/rate-of-descent control	w. Assess flight path alignment with runway and cross-track velocity during flare x. Assess pitch attitude and rate-of-descent during flare y. Assess aircraft alignment with runway centerline as aircraft approaches touchdown z. Assess touchdown attitude and rate-of-descent a.' Assess nose rotation rate b.' Assess directional control during rollout c.' Assess deceleration to nominal taxi speed
3. Assess/diagnose Operational Conditions	a. Assess forecast and reported weather conditions in the terminal area b. Assess the relative position, direction of flight, and rate of closure of	f. Assess traffic density and approach scheduling for destination airport g. Continue 3a h. Continue 3b	k. Assess runway visual range l. Assess wind direction, velocity, and shear effects m. Assess turbulence	p. Continue 3l q. Assess external visual reference for executing landing maneuver r. Continue 3m s. Continue 3n

Generic FM Function	Requirements During Penetration	Requirements During Initial Approach	Requirements During Final Approach	Requirements During Landing
	b. (Continued) other aircraft in the immediate surrounds c. Assess the availability and current operations status of navigation aids in the terminal area d. Assess reported runway conditions at the destination airport e. Assess the availability and current operationg status of landing aids and safety facilities at destination airport	i. Assess operating peculiarities, if any, of ILS/DME facility j. Assess terrain features in immediate vicinity of assigned approach pattern	n. Assess terrain and/or obstacle clearance o. Continue 3i	
4. Assess/diagnose Aircraft Subsystem Operation	a. Determine overall readiness of the BWLS for low approach and landing b. Detect incipient malfunctions and/or degraded operating modes in LVLS components	g. Continue 4b h. Continue 4c i. Assess configuration of aircraft lift/drag devices j. Assess on-line configuration of AFCS and guidance signal source selection	q. Continue 4b r. Continue 4c for selected landing maneuver control mode s. Assess AFCS' performance during glide slope capture and tracking to authorized DH t. Continue 4l	w. Assess aircraft response to manual control inputs x. Continue 4b y. Assess operation of thrust deflectors and/or drag devices during rollout z. Assess performance of wheel brakes

Generic FM Function	Requirements During Penetration	Requirements During Initial Approach	Requirements During Final Approach	Requirements During Landing
	c. Assess the impact of malfunctions and/or degraded operating modes on the approach plan d. Assess adjustable nose position e. Assess wing sweep position f. Assess operation of environmental control system during descent (particularly, depressurization rate)	k. Assess AFCS performance during localizer acquisition and stabilization l. Assess auto-throttle system performance m. Assess center-of-gravity location n. Assess landing gear position and down lock status o. Assess adjustable nose position for final approach p. Assess wing sweep position for final approach	u. Assess operation of rain removal system or other auxiliary systems (e.g., pitot heat) as required v. Continue 4i	
5. Resolve Flight Progress Decisions	a. Resolve low approach commitment decision	b. Resolve final approach commitment decision	c. Resolve landing commitment decision	d. Resolve landing maneuver abort decision
6. Resolve Non-routine and Emergency Action Decisions	a. As required by the outcome of assessment/diagnostic activities	b. Continue 6a	c. Continue 6a	d. Continue 6a

SECTION 3

IMPLEMENTATION OF FLIGHT MANAGEMENT FUNCTIONS

Two general study objectives are served by the materials presented in this section. The first is to apply the LVLS design concepts and operational employment considerations outlined in Section 1 to the development of statements of how FM activities might be carried out in projected SST approach and landing operations. The second objective is to relate the FM activities to such concurrent operations control functions as flight control and aircraft subsystem control and to provide some illustration of how FM problems arise and are resolved in the operational context.

A brief discussion of crew role assumptions and general mechanization concepts adopted for SST FM activities is given first. The term "mechanization" is used here in its broadest sense to refer to any configuration of means, including crew members and operating procedures as well as equipment, which may be used to implement system functions. The discussion will emphasize crew participation in FM functions and the extent to which they are supported by flight deck instrumentation, airborne computing and/or data processing equipment, reference materials, fixed operating policies and procedures, etc. The sequence of events occurring in an approach and landing at Dulles International Airport and the operational conditions assumed is presented in the Appendix to provide a more concrete frame of reference for illustrating the development and resolution of specific FM requirements.

Crew Role Assumptions and Mechanization Concepts Adopted for Flight Management Functions

In any systematic consideration of the means required to implement system functions in man-machine systems, issues arise regarding the assignment or allocation of functions to either man, machine, or man-machine components. Such issues are seldom straightforward or easily resolved on the basis of explicit and widely accepted criteria, and these difficulties are compounded in FM activities by considerations of "responsibility" and "authority". With considerable oversimplification, it can be said that responsibility has to do with the consequences or effects of system performance and involves the notion of accountability for these outcomes; authority has to do with the means provided for direct and effective control over the system being managed.

The general position underlying the present study is that issues expressed in terms of "allocation of functions to man <u>or</u> machine" or "degree of automation" are misleading in dealing with "command" or "management" functions in manned systems. Such functions are distinguished more by the assignment (or assumption) of responsibility for achieving system performance objectives and satisfying established safety and economic constraints than by the means employed. It is here asserted that this responsibility can only be assumed by people, in this instance, the pilot-in-command. When severe demands are imposed on their ability to make the necessary judgments and decisions, provisions must be made for more adequately supporting management/ command personnel. Corresponding provisions must be incorporated into the system design to give the pilot-in-command the necessary authority to implement management decisions, e. g., provisions for entering command data and/or effecting corrective actions.

This assertion should not be construed as imposing arbitrary constraints on the extent to which particular component functions of FM can be mechanized or automated. It simply means that even in the hypothetical case of a fully automated system, the pilot-in-command must be equipped to assess the overall flight situation and the particular conditions encountered and to determine the manner in which the system will be employed (e.g., the on-line configuration of equipment units and their operating mode) as well as any corrective actions necessary to achieve FM objectives. No restrictions, as such, are thus placed on the degree of automation of such system design features as self-monitoring and automatic mode switching or disconnect. System design provisions of this sort are seen as one means of supporting the pilot-in-command.

In accordance with this general position statement, mechanization concepts adopted in the present study for FM functions are outlined in what follows by clarifying crew participation and identifying the kind of support expected to be provided to the pilot-in-command in the projected SST landing system. Three levels of crew support were distinguished to facilitate this discussion:

1. Unaided - This category applies whenever specified FM requirements must be satisfied by the pilot-in-command with no assistance from airborne data processing and/or display equipment provided for management-specific functions. The use of flight deck reference materials, i.e., charts, data sheets, documents, etc., may be available, however, for use as performance guides.

2. Mechanized - This category applies when some portion of the FM specific data processing is accomplished by airborne equipment, but both equipment set-up and processing operations are directly controlled by the crew. An example would be a pilot-initiated system readiness check, entailing

a programmed sequence of equipment operating status checks with the crew selecting each test sequence and interpreting and/or evaluating the readouts obtained.

3. Automated - This category is reserved for component data processing and/or action decision functions executed under computer or stored-logic control and not requiring crew initiation or operating control. Crew role with respect to automated functions would be limited to accepting/rejecting (or otherwise responding to) warning, advisory, and status readouts in accordance with such factors as credibility judgments or firmly established operating policies.

Mechanization concepts adopted for FM are derived from the baseline landing system design features and are introduced for the six basic FM functions in the subsections which follow. More specific FM requirements are then located within the context of the approach and landing to Dulles International Airport to further clarify crew participation and to illustrate some specific sources of FM data and some possible outcomes of component diagnostic and decision functions.

Implementation of Flight Progress Assessment Functions

Flight progress assessments, as indicated in Section 2, are concerned, primarily, with the ongoing question of where the aircraft is in relation to where it should be and to where it should be going to achieve immediate flight path control objectives. The principal flight path control parameters which are pertinent to this concern are cross-track error, along-track error, altitude error, ATA error, and discrepancies of any sort in flight path projections (e.g., velocity vectors or track projections). Flight path control objectives are set, initially, by the assigned enroute course to the terminal entry point, then by the clearance given by approach control, and finally by terminal area maneuvering instructions (e.g., radar vectors) and the assigned ILS approach plan. The continuous assessment of aircraft position and movement with respect to these objectives is accomplished by the crew. Supporting flight deck instrumentation, reference materials, and advisories received from ATC facilities are outlined below.

During the intial portion of the penetration segment, data for flight progress monitoring will be available from the Inertial Navigation System (INS) for display on both the INS Display Panel (IDP) and the Horizontal Situation Indicator (HSI). Data items available by crew selection on the IDP are listed in Table 5. At the same time, INS derived magnetic heading, true heading, drift angle, track angle error, and cross-track deviations are available on the HSI.

At some point during this phase segment, the primary navigation reference for flight control is transferred from the INS to the external, VOR/ILS radio navigation system. It is assumed that both (Captain and 1st Officer) HSI's will now present selected radio navaid data, although the selection of INS-referenced data on one of these instruments is available as a crew option. In any case, digital readouts of INS data will be concurrently available on the IDP. The extent to which INS data can or will be used for flight progress monitoring in the terminal area is still an unresolved issue. Since this capability is a development item and radio aids in the terminal area currently provide the most accurate source of navigation/guidance data, the use of INS data after the switch-over to VOR/ILS is not considered in this report. It should be noted, however, that the INS is capable of providing cross-track acceleration with respect to the localizer beam and its use as a means of detecting localizer irregularities, as a low pass filter for smoothing beam fluctuations, and as a localizer alignment memory device when the beam fails, is being considered.

Table 5. Summary of Display Presentation

Data	Range	Resolution
Present position, latitude	$90^{o}N$ to $90^{o}S$	0.1 arc minute
Present position, longitude	$180^{o}E$ to $180^{o}W$	0.1 arc minute
Waypoint latitude	$90^{o}N$ to $90^{o}S$	0.1 arc minute
Waypoint longitude	$180^{o}E$ to $180^{o}W$	0.1 arc minute
True heading	0^{o} to 360^{o}	0.1 degree
Ground speed	0 to 2000 knots	1.0 knot
Drift angle	0^{o} to $\pm 45^{o}$	0.1 degree
Cross-track deviation	0 to $\pm$100 nm	0.1 nm
Present track angle	0^{o} to 360^{o}	0.1 degree
Track angle error	0^{o} to 180^{o}	0.1 degree
Distance to waypoints	0 to 9999 nm	1.0 nm
Time to waypoints	0 to 200 min	0.1 minute
Wind speed	0 to 300 knots	1.0 knot
Wind direction	0^{o} to 360^{o}	1.0 degree
Course change warning	1 to 3 min (shop adjust)	-
Course change	0 to 1 min (shop adjust)	-
Waypoint code select	0 to 7	-

Progress along the assigned track is monitored by reference to time and/or distance-to-go readouts available from the INS or to DME readouts after the transition to VOR source data. Ground speed is also available from the INS and may be used to assess the anticipated arrival time at control points (e. g., the TEP) against established ETA's. It should also be noted that the aircraft will enter the more closely controlled terminal area during this phase segment and its progress will be carefully followed by ground radar facilities. Advisories with respect to along-track error will thus be available from controllers on assigned VHF frequencies.

Vertical flight path monitoring will be accomplished by reference to barometric altimeters and vertical speed readouts throughout the descent and level-off at initial approach altitude. Following glide slope acquisition, glide slope deviation indicators on both the HSI's and Attitude-Director Indicators (ADI) will provide the primary status information for the low approach to the assigned runway. The glide slope deviation display is desensitized below 200 feet so that indicated deviations are proportional to actual flight path deviation in feet; gain reduction programming as a function of radio altitude is used to accomplish this desensitization. Radio altimeters will be available for more precise monitoring of altitude above the ground and annunciators will illuminate to indicate arrival at pre-selected Minimum Decision Altitudes (MDA). A "rising runway" display element on the ADI will provide radio altitude over the runway during the last 200 feet of the approach.

Horizontal flight path monitoring will also shift from the HSI to the ADI following completion of the localizer acquisition and stabilization maneuver. An expanded localizer deviation display on this instrument is included in the baseline system concept and provides for more sensitive monitoring of the direction and rate of lateral deviations from the assigned localizer course. The expanded scale is also expected to support the rapid assessment of trends, i.e., that the aircraft is diverging from, converging toward, or flying parallel to the desired course. No "excessive deviation" warning light system, such as the one being developed by Lear Siegler/Sud Aviation for the Caravelle, is assumed for the baseline system. [1]

With the exception of conventional marker beacon indicator lights for passage over outer, middle, and inner approach markers, all of the provisions for monitoring and assessing flight progress during the approach and landing are described above. Approach progress annunciators are available and may be of some value in assessing flight progress, but basic information provided by these indiators is the mode sequencing of the AP/FD system. They can also be used, however, to monitor such events as localizer and glide slope interception (capture), arrival at minimum decision altitude, and arrival at the flare initiation point. Notice that no head-up display of any sort is assumed (see Section 1 for rationale) and no independent runway imaging systems, such as Bendix Microvision or Sperry Beacon Vision, are expected to be available in the baseline system. Precision Approach Radar (PAR) will be available, however, and whenever the assigned localizer course coincides with the PAR final approach course, the controller could provide advisories concerning localizer and glide path deviations whenever established flight path limits were exeeded. PAR advisories are typically terminated when the pilot reports sighting approach lights or when the aircraft reaches 200 feet.

---

[1] These lights, located adjacent to the ADI would provide a warning indication whenever lateral deviations exceeded 15 microamps of beam signal or when glide slope deviation was greater than 50 microamps.

Implementation of Aircraft Performance Assessment Functions

As indicated in Section 2, aircraft performance assessments are directed toward the manner in which certain flight maneuvers and flight path control actions are executed. The identification of basic flight control parameters used in these assessments is quite straightforward, since this entails a consideration of such well established aircraft states as airspeed, attitude, altitude, velocity vectors, relative position and alignment of aircraft axes, and corresponding rates of change in the values of these parameters. The difficulty in attempting a brief characterization of how aircraft performance assessments are accomplished stems from the variations in individual pilot techniques, airline operating practices, situational factors, etc., which determine the relative significance attached to such parameters and the assessment criteria applied to identify marginal or out-of-tolerance conditions.

In a few instances, specific provisions for determining the extent to which established flight control requirements are being satisfied can be identified. For example, a "speed error" display element on the ADI, driven by the autothrust computer, indicates the agreement of the actual, instantaneous speed of the aircraft with the command airspeed selected to govern the airspeed control function. In addition, reference values can be set for indicated airspeed, heading, altitude, and vertical speed to facilitate monitoring of these parameters. And in a somewhat different but related sense, the flight director command elements provide a means for monitoring/assessing aircraft performance since the manner in which pitch and roll commands are being satisfied is represented on this display.

For the most part, however, flight deck instrumentation and associated sensor and data processing provisions are limited to showing present aircraft status on the parameters of interest. It remains for the pilot-in-command to derive and apply assessment criteria for judging the effectiveness, safety, suitability, etc., of the aircraft's behavior for a given maneuver and/or under the operational conditions which actually obtain. How much lag in responding to a glide slope deviation condition will be acceptable at altitudes below 100 feet? Is it safe to accept a pitch down maneuver for correcting glide slope deviations at these altitudes? How much lateral displacement from the localizer and/or glide slope is tolerable at various points along the approach? Such issues must be resolved by the crew for the conditions actually encountered and this will often be done on the basis of inexplicable or idiosyncratic criteria.

Provisions for aircraft performance assessment in the baseline system, then, include:

1. The basic flight control instrumentation, i.e., an advanced ADI (such as the Sperry AD-200 or Collins FD-109) and HSI, airspeed indicator, barometric altimeter, vertical speed indicator, inclinometer, and turn rate indicator.

2. Digital readouts and cursor indices of selected airspeeds, headings, altitudes, and vertical speeds.

3. Radio altitude and vertical speed indicator.

4. Clock/elapsed time indicator.

5. A stick-shaker angle of attack warning.

6. Control surface position indicators for all movable flight controls.

It is important to note that certain display elements which are often cited in the literature on new developments in landing system displays are not assumed to be available in the baseline system. These include flight path markers (or velocity vector, projected ground impact point, etc.), flight path angle, runway image or aiming point, angle of attack index, rollout steering commands, and runway remaining indices.

Additional provisions for aircraft performance monitoring are available in the form of various flight deck reference materials. Data sheets establishing subsonic descent schedule airspeeds and expected rate-of-descent performance as a function of landing gross weight and ambient conditions are examples of these materials. Additional reference data includes landing gross weight restrictions, prescribed airspeeds for various landing configurations and weather conditions (i.e., gusts, high ambient temperatures), nominal thrust settings for descent, altitude holding, final approach, go-around, etc., and deceleration performance (runway distance required) for various landing configurations and runway conditions. Other criteria for assessing critical maneuvers, e.g., timing of flare initiation in terms of altitude and/or position relative to intended touchdown point, are available to the crew only through recall of past experience and training and are applied in accordance with the dynamics of the specific flight situation.

Perceptual cues available from extra-flight deck visual reference will be of considerable importance in assessing aircraft attitudes and flight path dynamics at the Category II decision height and throughout the flare maneuver, touchdown and rollout. Under Category II conditions adequate perceptual reference <u>must</u> be available for executing the landing maneuver, but even under Category IIIa conditions <u>some</u> visual reference will be possible and it will be used to the extent that it supports flight path control and/or assessment functions. The problem of determining the particular visual cues and acquisition factors which, in fact, constitute "adequate" external visual reference is an ongoing concern and is currently receiving considerable attention. But specific requirements have not been firmly established or widely accepted.

The general character of the means for assessing aircraft performance during the critical segments of the landing sequence, and some of the potential problems associated with the use of the limited visual cues expected to be available, is clearly illustrated in the following excerpt from a recent paper by R. H. Beck of ALPA's All Weather Flying Committee (ref. 5):

> If we revert back to the previously mentioned optimum set of circumstances - the ideal approach conditions, we will find the aircraft is progressing satisfactorily down the approach path. The Captain is either flying manually by using the raw data of the localizer and glideslope as well as computed command information, or is on automatic and is monitoring the response of this automatic equipment to the ILS inputs and is, in fact, exercising complete control of the flight. Since the airplane is and continues to remain "in the slot", he has just about formed an opinion regarding the success of the approach.
>
> The First Officer meanwhile, is performing his assigned functions, such as monitoring his panel instruments and calling out certain altitudes as the aircraft progresses down the glide slope. ...As the DH is approached, the First Officer will now begin to pick up fragmentary outside cues and will then usually direct his entire attention toward identifying them.
>
> The basic concept of tracking should be mentioned at this point. The aircraft is doing one of three things: tracking on or parallel to, tracking away from, or tracking toward a desired path over the ground. At approach speed and at a low altitude with restricted visibility, tracking is determined by first observing a known object such as a light, for example, then observing another light or series of them and comparing them with what is first seen.
>
> Experience has shown that, in order to do this, a pilot must see a horizontal segment of lights equivalent to about three seconds of reaction time. At approach speed of 140 knots, the required segment will be at least 700 feet. To mentally digest this information, evaluate it, and decide whether the aircraft is or is not tracking as desired may take a fraction of a second or it may take several seconds, depending on the clarity, readability, and simplicity of

the cues. If we deviate from our optimum theoretical approach for a moment, this delay can be complicated by having the plane in the not uncommon position where it is yawed to the left, for example, due to a crosswind, and the autopilot has placed the plane to the left of the centerline. Fragmentary cues begin to appear to the First Officer outside the window to his right. Since the First Officer may never have been exposed to a situation like this before, either under actual conditions or by simulation, there is grave doubt as to whether he will be able to quickly and accurately determine lateral tracking velocity or a positive tracking tendency. An actual situation such as this occurred recently during conditions of variable low visibility, the only difference being that the aircraft (a Boeing 727) was actually on localizer and on glide slope. The First Officer called out "Approach lights in sight to the right". The Captain then looked up to the right across the nose of the airplane. Due to the reduced cockpit cutoff angle caused by the left crab angle, he was unable to see the last portion of the approach lights. Furthermore, he was completely unable to assess any rate of lateral tracking, even if there had been any.

Implementation of Operational Conditions Assessment Functions

Significant operational conditions for this subset of FM functions include weather conditions in the terminal area and in the immediate vicinity of the landing runway, separation from other air traffic, terrain features and structures affecting altitude minimums or navigation tolerances, the operating status, and characteristics of available ground navigation and guidance facilities, and the availability and status of landing aids and related facilities at the destination airport. Status information on these conditions is available to the crew, for the most part, in the form of pre-flight briefings and data sheets, supplemented by inflight radio communications with company dispatch officer and/or ATC facilities. Airborne sensor and data processing equipment supporting this function is limited to such items as wind direction and velocity readouts from the INS, weather and ground mapping radar, drift angle and groundspeed readouts, and outside air temperature indicators. In the last moments of the approach, direct visual reference to environmental conditions, runway conditions, etc., will be available.

The detection and assessment of weather phenomena, particularly conditions affecting effective runway visual range and flight control (e.g., crosswinds, wind shear, gusts, etc.) is of critical importance to the success of approach and landing operations. This function is performed by the crew on the basis of periodic reports and advisories of measured ceilings, RVR and winds at the destination airport received via radio voice communications. Weather radar might be used early in the approach to anticipate and avoid heavy preceipitation and turbulence but would not typically be used after establishing an intercept heading for the ILS localizer. In some instances, evaluative information would be added to reported weather data, as when the flight is advised that airport weather is marginal or clearly below specified minima. For the most part, however, the crew must detect trends and unstable situations and apply their own judgment to simple status reports. Reports provided by other flight crews in the immediate flight environment and attempting landings at the destination airport are an important additional source of weather data.

Under the Category II and III conditions assumed for this study, the continuous assessment of potential flight path conflicts with other air traffic must also be based on advisories received via radio voice communications from ATC facilities. Adequate aircraft track spacing and/or altitude separation is the primary responsibility of ground control, but the crew will, understandably, attempt to follow the traffic situation very closely to ensure adequate safety margins. To some extent, the monitoring of control instructions, advisories, position reports, etc., concerning other aircraft will provide the crew with additional status data on other air traffic. No collision avoidance system or device is included in the baseline system, although considerable effort is currently being applied to the development and evaluation of such systems for airline operations.

Radio voice communications with company dispatch offices and/or ARINC-operated flight advisory services are also the primary means of obtaining updated operating status information on ground facilities and runway conditions. The latter would also be routinely reported to the flight when landing clearances and instructions were requested. The significance of any changes in the status of these facilities must be assessed by the crew.

Terrain features and structures will be accounted for primarily by reference to terminal area maps and charts, such as current approach plates, and coordinated with the flight progress monitoring discussed earlier. Airborne radar in the ground mapping mode and radio altimeters will also be useful for this purpose in some situations and advisories will be available from ground radar flight following services.

Implementation of Aircraft Subsystem Operation Assessment Functions

In the terminal area and in the vicinity of the landing runway many of the aircraft's subsystems will be employed in modes of operations not previously utilized. As a result, the crew will require information concerning the ability of these systems to perform in accordance with acceptable performance envelopes. In most cases this will be provided to the crew via a set of malfunction indications associated with each individual subsystem (e.g., a warning horn and blinking light in the landing gear handle to warn against some unsafe position of the landing gear).

During terminal area operations and the approach to the destination airport, a variety of FM assessments are required (see Table 4). In all these cases the role of the crew is basically to determine the overall readiness of the systems, the effect of any malfunctioning mode of operation, and to assess the operation of subsystems.

Operation of the LVLS is of prime importance in the final portion of the flight profile. All components making up this system feed their inputs into a test logic computer which evaluates their reliability and provides the crew with malfunction or out-of-tolerance indications. Information on the internal functioning of the equipment is provided by a panel of annunciator lights which indicate readiness of the various subsystems (e. g., if the automatic system test is "no go" the annunciators would illuminate red to alert the crew to a malfunctioning component and elicit some action decision). On the basis of the warning the crew will then be required to determine (e. g., by cross-checking) if the equipment has in fact failed, and if this can be ascertained, then what effect the malfunctioning component will have on the total system performance. The final step in the process is to examine the outcome in light of the existing conditions at the terminal airport to determine what effect the malfunction has on the final outcome of the flight (i. e., will the aircraft still be able to land at the destination airport, or will a diversion to an alternate air terminal be required?).

In the adjustment of the variable nose and wing sweep, the crew will be provided with information on control position for that subsystem, and will receive direct visual feedback where such is available and through the response of the aircraft to the configuration change. Such is the information from which the crew must assess the operation of these particular configuration changing subsystems.

An important subsystem, the environmental control subsystem, is provided with a series of indicators which monitor the important parameters (e. g., rate of depressurization, cabin temperature, ozone content, etc.). These indicators of system state are graduated and color coded to provide the crew with a quick assessment of the operation of the system.

The Automatic Flight Control System (AFCS) is operationally defined as a part of the LVLS during the final approach to the runway. For that reason it is vital that the AFCS be "checked out" prior to the commencement of the final approach. The control box provides an indication of the configuration of the system (i. e., the source of the input signal). Another important subsystem, the autothrottle, must also be checked to determine its readiness for the final approach. It is assumed here, that each of these systems will have a built in test logic circuit which provides internal testing of the subsystems, and drives a warning annunciator in the event of a failure or an impending failure. If no such warning is displayed the crew must rely upon the information received from the other cockpit instrumentation to evaluate performance of the subsystems and their effect on the landing operation.

Assessment of the other subsystems is usually based upon performance of the system and the ultimate response of the aircraft. For these systems a malfunction is immediately obvious. For example, if during landing the wheel brakes were to fail, or if one side were to freeze, the aircraft response would immediately signal the crew to the non-routine situation. Wheel brakes usually are hydraulically actuated and the crew might receive feedback information early (prior to touchdown) through the wheel pedal actuators (i. e., a loss of pressure would result in the easy free travel of the wheel pedal actuators).

Assessment functions are the result of the crew's desire to anticipate equipment condition (i. e., "staying ahead of the aircraft"), so that if in fact some malfunction exists, sufficient time will be available to the crew to select the optimum alternative course of action. In almost all instances the crew possesses, because of the required training and orientation in the specific aircraft, a mental picture of how particular subsystems should operate, and how the state of the aircraft will change when these are employed. If the aircraft does not react appropriately, the crew should recognize the deviation and be able to associate it with the operation of a particular subsystem. If it can not be repaired or by-passed, with no resulting loss of capability, the crew is faced with a resolution function to be discussed shortly.

In the event that the crew is able to detect a malfunctioning or out-of-tolerance subsystem, cases exist where the response required by the crew is invariant (i. e., some standard procedure of performance has been established and the crew merely complies). It is not this particular type of situation that we are primarily concerned with at the moment, but rather that group, which because of the particular circumstances, calls for some response which is a function of the circumstances. Obviously this group of malfunctions are more critical and demanding upon the crew, as they must assess the malfunction, weigh the alternatives, and then select some appropriate line of action.

Implementation of Flight Progess Decision Resolution Functions

Throughout the flight profile a continuing requirement exists to assess flight progress. Previous discussion describes the manner in which this is accomplished for the baseline system. It was pointed out that the requirement imposed on the crew to evaluate abnormal states in light of overall system information and then to decide on appropriate action. There are no provisions for assisting the crew in making the decision. Decisions are usually based upon acquired information and the anticipated effect such flight deviations will have on the overall outcome of the flight.

During terminal area operations the crew will be required to assess the aircraft's approach to the terminal airport and the subsequent maneuvers toward a landing, and resolve in their own minds that the aircraft is in fact complying with pre-detemined criteria and that no action other than that normally followed is to be taken. Major decisions are those which resolve the initial approach commitment, the final approach commitment, and the decision to continue the landing to touchdown. The decision to abort the approach and "go-around" are the major alternatives considered continually throughout this final flight phase.

In making these decisions, the crew will utilize available cockpit information in order to bring as much information as possible to bear on the situation, and then will, on the basis of their past experiences, select the solution concept which appears optimum to them at the moment. Except for information from flight instruments the crew will be unaided in their decision making other than in those instances where their action is dictated by some specific "operating procedure", and will necessarily be faced with the task of assimilating as quickly as possible the information available (i.e., degree of deviation from some preconceived flight path as well as that information available through visual cues) and formulating a course of action. Specific decisions required during this particular flight segment, will entail relatively speedy evaluations. On the basis of the flight progress assessment a CONTINUE or DO NOT CONTINUE decision will have to be made.

It can be seen that to some degree there is a potential for wide variance in the manner in which this function is accomplished by different crews. This is especially true while the aircraft is operating in low visibility and ceiling conditions, as each Captain usually has some "minimum" which he will accept; such minimums being derived from perceived personal capability.

Implementation of Non-routine and Emergency Action Decisions Resolution Functions

The above paragraphs describe the crew as constantly evaluating and assessing the operation of the aircraft and its subsystems, as well as the overall performance of the aircraft within the context of the larger system (i.e., the operating environment). The results of these assessment functions can be classified into a small number of alternative groups; namely, (1) all is going according to plan, (2) some deviation exists but some alternate method of operation is available so that no further action is necessary or called for other than appropriate reconfiguration of the suspect subsystem, and finally (3) there is that group of situations in which the deviation is such that there are no normal or parallel systems existent which will allow continuation under normal circumstances, and thus some operation other than the norm must be utilized in order to maintain the safety and integrity of the flight. For present purposes, a non-routine situation is one in which the aircraft is unable to complete its flight to its originally scheduled destination, due to existing weather or traffic conditions at the destination airport not necessarily due to a malfunctioning component. All three situations are considered within this function since in all cases a deviation has been detected and some further action is now necessary. The crew is not typically provided with any mechanized assistance for these functions, but rather must call upon their store of experience and knowledge of the systems under scrutiny. This is primarily a judgmental function. Once an action has been decided upon and then implemented, the processing loop must be re-entered (i.e., if the system is reconfigured to compensate for the malfunctioning component, an assessment of flight progress and subsystem operation must be repeated -- if the outcome is satisfactory, no further action is required. However, a "no go" situation would again require an action decision).

For a large number of the malfunctions that the crew is apt to encounter, the carrier will in most instances have developed a set of "Standard Operating Procedures" (SOP) or "Emergency Procedures" (EP) which the crew is expected to follow if some specific deviation occurs. However, it is not with the group of such recognizable deviations with which we are concerned. We are more concerned with those decisions that must be made in areas not covered by standard policy; decisions which must be made instantaneously or at least in a very short time period, and must be the result of as thorough an analysis of available information as possible. It is for this reason that these functions will be closely examined in subsequent analyses, within the context of the landing and approach maneuver to determine the effect of "time compression" (i. e., a constant number of functions to be completed in a diminishing amount of time) on decision quality in non-routine or emergency conditions. It may be that a problem area indeed exists and that the only way an improvement can be made is to supply the crew with some type of mechanized assistance in the form of command displays or a more complete set of procedures to follow. For the baseline system which is herein described no such assistance is provided. While it is easy to say that man is capable of coping with any situation that might arise, there is no real scale of workload currently available. Hence, it is very difficult to determine man's need for any such assistance. Only when some performance measure is closely examined can more concrete statements be made on the adequacy of support provided the crew in this area.

APPENDIX A

OPERATIONAL SEQUENCE DESCRIPTION OF AN SST APPROACH AND LANDING

Introduction

In this Appendix, an attempt is made to describe the operational sequence of activities as they might occur in using the baseline BWLS in a low visibility approach and landing to Dulles International Airport. Emphasis is placed upon SST crew activities with special focus on Flight Management (FM) tasks.

A hypothetical SST flight was described in a previous report (ref. 2) which covered, in a general way, the entire flight profile. The primary concern of this study is with approach and landing and hence we have tried to expand upon those phases more than was possible in the aforementioned report.

The operational sequence description developed herein, should serve several purposes. First it should, by illustration, clarify the character of flight management; second, it will provide a preliminary data base for the analysis of FM functions performed during the critical approach and landing manuevers; and third, it will serve as a guideline for deciding context requirements for certain simulation research at Ames Research Center. Dulles International Airport was selected as the destination terminal for the hypothetical flight since an approach and landing to that airport can be simulated with existing instrumentation at Ames.

To illustrate the mechanization concepts by which operations control functions, especially FM are performed, reference is made to flight deck instrumentation and controls, cockpit reference materials, and communications used by the crew in satisfying assumed task requirements throughout the flight profile. A brief discussion of the flight is presented first in order to introduce the flight plan and to establish initial conditions of the designated SST flight. The sequence description itself will commence at the penetration phase segment and terminate with the landing rollout of the aircraft.

Flight Plan (London to Dulles International Airport)

The flight plan prepared for the hypothetical SST transoceanic flight from LON to DIA, is presented in Figure A-1. Flight plans are prepared by company operations and assigned to a designated aircraft and crew for execution. Establishing the general objectives for the overall flight plans such as the one illustrated influence crew performance throughout the flight profile. After reviewing the flight plan and assessing operational conditions, particularly forecast weather conditions for the terminal area and temperature and wind conditions at assigned enroute flight levels, the crew coordinates any final revisions with the flight dispatch office and accepts the plan. The crew then computes the necessary flight data, such as fuel requirements, optimum power settings for takeoff and climbout, climb and descent schedules, and any special fuel requirements and/or time checks affecting the transonic acceleration maneuver. When these detailed flight plan activities are completed, the flight plan is filed with ATC for clearance.

After an initial clearance and assigned engine start time is received, the crew proceeds to the aircraft and completes the pre-flight inspection and pre-start checklist. Flight plan clearance may be delayed until the crew is in the aircraft with all flight preparations completed and will

9261-00090 11/62

ORIGINAL (B COPY) → F/O FOLDER
COPIES → STATION FILE

FLIGHT PLAN & CLEARANCE

TRIP / DATE	SCHEDULE	A/C NO.	TYPE CRUISE	CAPTAIN	TYPE OF FLIGHT	TRIP IDENT.	A/C TYPE	TAS	POINT OF DEPT.	CRUISING ALTITUDE	ROUTE OF FLIGHT	ETD	TIME ENROUTE
SST 1	FROM LON T.O. Z / TO DIA LND Z	N 2707	2.7		IFR	SST 1	B 2707	1550	LON	FL 700	G-1, UG-1 SNN 53° N 15 W GC CTL 1146 ACK J-62 JFK J-6 EMT V-39 HRN → DIA		

DESTINATION FLIGHT TIME ANALYSIS / POSITION REPORT / FUEL ANALYSIS / HOWGOZIT DATA

FLT LEVEL	TRK *	WIND/EWC D/V #	MACH NO.	FCST TEMP	TAS	GS FCST	DIST	TIME # HR MIN	TIME FCST HR MIN	FCST ETA	3 LTR POS	TIME	CRUISE ALT 100'S	POSITION NAME	TIME	FCST FUEL CONSUMED/ REMAINING	ACT FUEL BURN/ REMAINING	TOD FUEL SCORE	DIST TO GO	REMARKS
										/	← T.O. TIMES							← FUEL		
CLB							107				LON			BRECON						
							069				BCN			STRUMBLE						
							148				STU			SHANNON						
											SNN			T/S GATE						
							375													
											TSG			53° N 15 W						
							180				15W			53° N 20 W						
700		270/20	2.7	-55	1550		360				20W			52°30'N 30W						
							365				30W			51°10'N 40W						
							395				40W			49° N 50 W						
							450				50W			45°30'N 60W						
							360				60W			CTL 1146						
							147				146			NANTUCKET						
							175				ACK			KENNEDY						
							163				JFK			WESTMINISTER						
							36				EMT			HERNDON						
							3				HRN			WASHINGTON						
											DIA									

TOGW CALCULATIONS

TYPE OF FUEL	ENG TYPE	
INOP ITEMS		
FLAP SETTING	T.O.	T.O.
QNH	LOW QNH CORR.	
FLD PRESS. ALT	WIND	
RWY/SLOPE	/	/
EFFECTIVE WIND COMPONENT		
TEMPERATURE °C	°C	°C
1. RWY TOGW		
ANTI ICE/RAIN	−	−
2. CORR. TOGW		
A 3. FLD MAX/2 SEG CLMB		
4. MAX TOGW MIN 1-2, 3		
5. LESS REQ'D FUEL & WATER	−	−
6. DTW LMTD BY TOGW		
1. MAX LGW RWY		
DEST FUEL	+	+
B 2. WATER-OIL-ADI	+	+
3. TOGW LMTD BY LGW		
4. LESS REQD FUEL & WATER	−	−
5. DTW LMTD BY LGW		
C MAX ZFW		
D 2-3 ENG ENROUTE DTW		

FUEL CALCULATIONS

FUEL TO DESTINATION		
ALTERNATE + RESERVE	+	+
EXTRA FOR		
REQUIRED FUEL		
STORED FUEL	+	+
T.O. FUEL		
ENDURANCE	HR MIN	HR MIN

SUMMARY

MAX WT BLOCKS		
MAX TOGW MIN A4 or B5		
MAX DTW MIN A6 B5 C or D		
	ACTUAL	ESTIMATED
TOGW		
LDG		
DTW		

ALTERNATE FLIGHT TIME ANALYSIS

ALTR	ROUTE	WIND	DIST	TIME HRS.	TIME MIN.	FUEL
	NO ALTERNATE	HRS AT DEST				

* TRUE MAG or GRID # AVG or TOTAL

TIME

AVG EWC

FUEL

REMARKS

ATTACHMENTS WEA DATA ☐ NOTAMS ☐ REMOTE CLEARANCE ☐ CLR. VALID UNTIL

IT IS CERTIFIED THAT THE INFORMATION APPEARING ABOVE IS CORRECT AND FROM AUTHORIZED SOURCES. ALL REQUIRED WEATHER REPORTS, NOTAMS, AND ADVISORIES FROM THE FLIGHT DISPATCHER ARE INCLUDED.

OPS. REP. CLEAR AUTH BY DISPATCHER

I HEREBY CERTIFY I HAVE FOUND ALL FACTORS WHICH FORM THE BASIS OF THE FLIGHT PLAN TO BE IN ACCORDANCE WITH REGULATIONS, AND MY BEST JUDGMENT AND CONCERN FOR THE SAFETY OF THE OPERATION.

DATE + TIME FILED CAPTAIN

Figure A-1. SST Flight Plan for hypothetical flight from London to Dulles International Airport then be received via radio voice communication in the following general form:

> ATC CLEARS SST ONE TO DULLES INTERNATIONAL AIRPORT VIA GREEN ONE AND UPPER GREEN ONE (G-1 AND UG-1) SHANNON, GREAT CIRCLE ROUTE TO CONTROL ONE ONE FOUR SIX, NANTUCKET, JET SIXTY TWO (J-62) KENNEDY, JET SIX (J-6) WESTMINSTER, VICTOR THIRTY NINE (V-39) HERNDON, DIRECT DULLES INTERNATIONAL AIRPORT. CLIMB TO AND MAINTAIN FLIGHT LEVEL SEVEN ZERO ZERO. STANDARD WOODLEY DEPARTURE. CONTACT DEPARTURE CONTROL ON ONE TWO ONE DECIMAL TWO (121. 2). SQUAWK ALPHA TWO ZERO ZERO ZERO JUST PRIOR TO DEPARTURE.

Readers interested in a general description of the flight activities during the takeoff, the climbout and the enroute portion of the flight are directed to the earlier report (ref. 2). A number of options are available in selecting a coastal penetration point and route to the Dulles terminal area considering noise abatement, air traffic densities, direct versus airways, etc. Since our concern is primarily with approach and landing operations, we have arbitrarily selected the route shown in Figure A-1. For present purposes it is assumed that the SST has completed the initial portion of the flight profile satisfactorily and is approaching the Nantucket VOR. Figure A-2 illustrates the portion of the flight remaining (i. e., from just prior to Nantucket until the aircraft reaches Herndon).

Penetration

Approaching Nantucket VOR the SST, will be at an altitude of approximately 45, 000 feet, just completing its supersonic deceleration. The inertial navigation system will still be providing steering commands to the Automatic Flight Control System (AFCS). The crew at this time selects a frequency of 117. 7 mc on the number one VOR receiver and identifies the Nantucket VOR (i. e., A C K and the course indicator

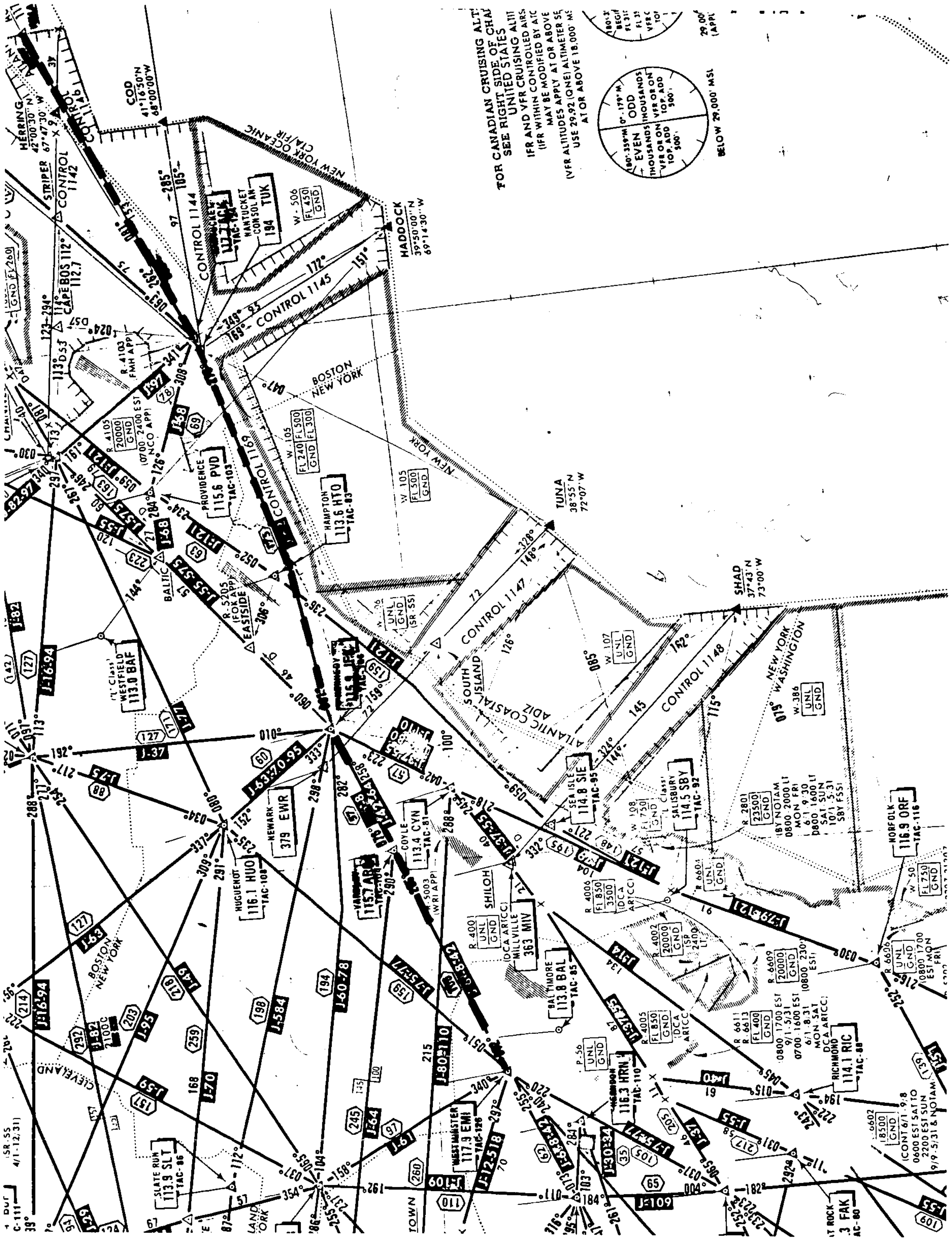


Figure A-2. SST flight profile during penetration phase would be set to 262 degrees. If the aircraft is receiving bearing and distance information from Nantucket VOR, the crew would transfer the source of the navigational information from the inertial system to the selected VOR system. Although the inertial system would continue to operate off line and provide aircraft position information, flight control correction signals would be generated from information received over the VOR system.

Control in the vertical plane would be by pre-selected descent profile, and in the horizontal plane by the AFCS system. The crew would probably monitor the operation of the AFCS using the HSI and the ADI to insure that the system intercepted and tracked the 082 degree radial of Nantucket. Upon reaching Nantucket VOR the crew would select 270 degrees in the course selector and the AFCS would turn the aircraft and track outbound along the new course. A DME reading of 105 nautical miles from Nantucket would signal the crew to tune in Kennedy VOR (115.9 mc). Once the station has been identified (J F K) the crew would select the 271 degrees in the course selector and the aircraft would automatically turn so as to intercept and track inbound on the 091 degree radial of the Kennedy VOR. The aircraft would continue its descent and would be at approximately 30,000 feet over Kennedy VOR. At that point the crew would select 258 degrees in the course selector and the aircraft would be turned to intercept and track this radial outbound from the station.

The next position, Yardley VOR on 115.7 mc would be selected on the second VOR receiver and identified (A R D). A course of 256 degrees would be selected and the number two VOR would be switched on line and the aircraft would then automatically turn to intercept this radial and track it inbound. Upon reaching Yardley a course of 255 degrees would be selected and the aircraft would track outbound toward Westminister VOR. Within range of the Westminster

VOR the crew would select 117.9 mc and identify (E M I). Upon selecting a course of 252 degrees, the aircraft would track inbound to the Westminister VOR (see Figure A-3). At this point the aircraft would be at approximately 10,000 feet completing the penetration phase of the flight.

In addition to the navigation and flight control functions described above, some special crew activities must take place during this phase segment. Diagnostic/assessment functions which must be completed prior, during, and after the maneuvers are discussed below.

During this phase segment the crew must reconfigure the aircraft so as to maintain optimum performance. This means that the adjustable nose must be lowered to provide the crew with adequate visibility during this integration with subsonic traffic, and must change the sweep of the wing so as to obtain the required subsonic aircraft characteristics. These adjustments in the aircraft configuration are accompanied by an assessment of the operation of the configuration changing subsystems (i. e., assess adjustable nose position and wingsweep position). One other important aircraft subsystem which must be checked for proper operation during this period, is the environmental control system particularly the depressurization rate).

It seems reasonable to expect that prior to starting descent the crew would assess the forecast and reported weather conditions in the terminal area, the availability and current operating status of navigation aids, the reported runway conditions, and the availability and current operating status of landing aids and safety facilities at the destination airport. Results of these assessments would determine whether to continue with the approach or to divert to the alternate. For purposes of this hypothetical flight it is assumed that these assessments have been resolved and the approach is proceeding according to plan. Since the

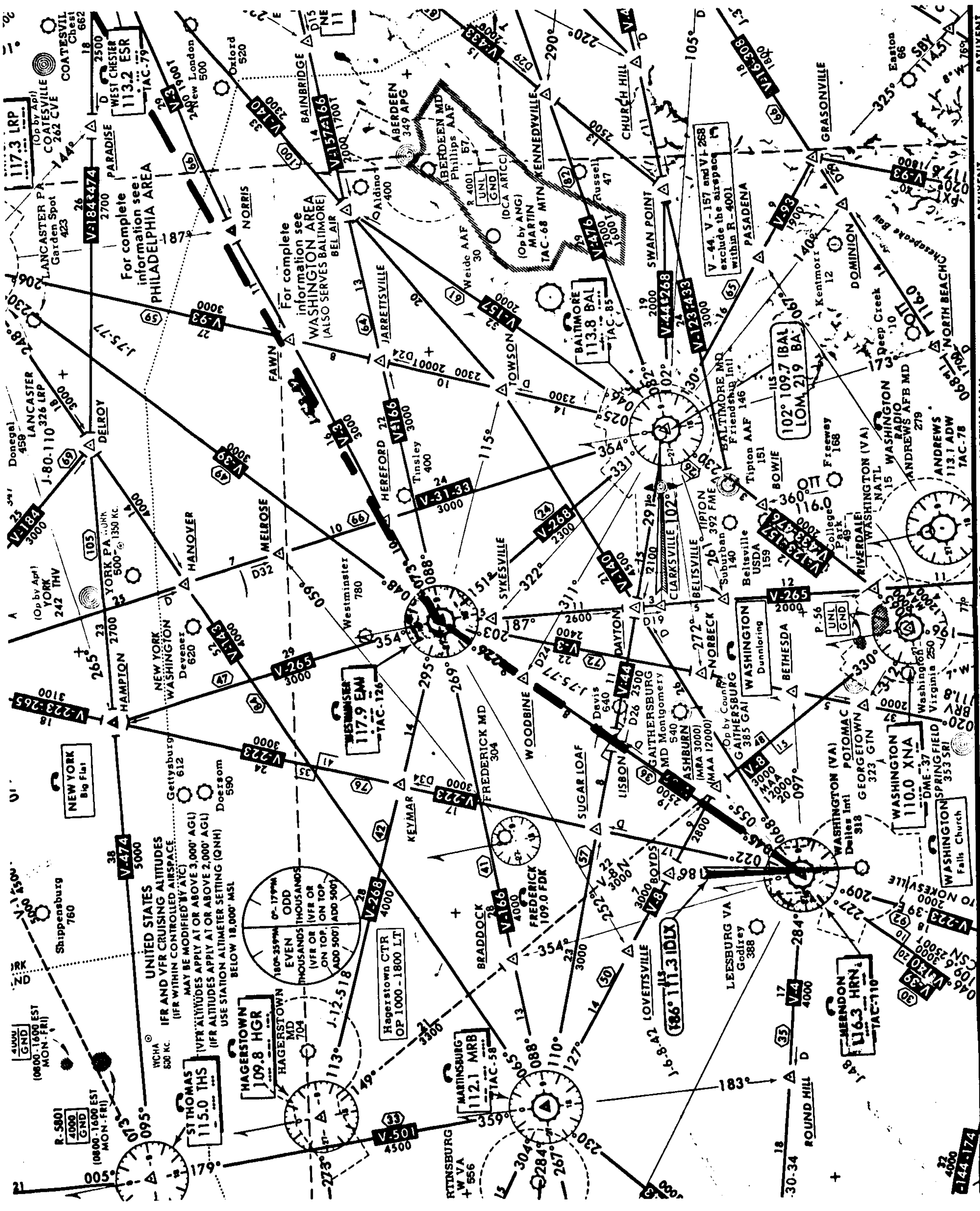


Figure A-3. Transition from penetration to initial approach appropriate equipment has already been selected and the necessary switching has been accomplished, the role of the crew becomes one of assessing the operation and performance of the equipment.

With the aircraft back in the VOR guidance environment the crew is provided with many indications necessary to the assessment and evaluation of the equipment. The HSI provides information on the aircraft's relative position to a selected course and provides a direct readout of any cross-track error. Throughout the penetration of the flight from Nantucket to the Westminster VOR the crew must continuously assess the assigned course to the terminal entry point at Westminster. It must detect any cross-track error conditions and determine the significance and probable cause. The crew must also compare or assess the letdown against the altitude clearance constraints, it must assess the rate of approach to the terminal entry point, and finally the actual time of arrival at the terminal entry point as compared to the estimated time of arrival. These assessments which deal with the flight progress of the aircraft along its planned route must be constantly repeated so as to maintain cognizance over the flight. In addition, the crew must continually assess maintenance of the descent schedule, airspeed and rate of descent, assess the thrust required to maintain descent schedule, the pitch attitude and rate, the airspeed against configuration constraints and terminal area operating limits, and select the optimum initial approach airspeed. These last assessments deal primarily with the effective operation of certain aircraft subsystems. The crew must monitor these subsystems and insure that they are complying with all constraints.

Even though the aircraft is flying under an IFR flight plan and is under the control of an air traffic controller, the crew still has the responsibility to watch for conflicting traffic. If such traffic is detected the crew must then assess the relative position, direction of flight, and rate of closure of these aircraft in the immediate vicinity.

For this hypothetical flight we have assumed that the terminal airport (i. e., the Dulles International Airport) has a low ceiling and low visibility condition, but that conditions do not warrant diversion to an alternate airport. As a result, one of the crew's functions will be to activate an enroute test of the SST landing system to insure that it is functioning correctly. Although the crew actuates the test, the test itself is completed automatically by the all weather landing system. The crew is provided with a display of the results, but at this point has no means of cross-checking them.

With the LVLS operating, and weather at the terminal airport above minimums, and with all other aircraft subsystems operating satisfactory, the crew resolves the decision and continues with the approach to the final destination. It should be pointed out that at any time between this point and the final landing the crew may decide to discontinue the approach and to either try again or to divert to the alternate airport. If at any time during the phase segment, one of the assessments had shown some non-routine or some emergency condition the crew would have had to resolve the situation utilizing whatever information was available in the cockpit. Just prior to leaving this phase segment the crew will be transferred from the Washington center enroute control to the Dulles approach control and assigned a communications frequency of 119.2 mc.

Initial Approach (see Figure A-4)

Once over Westminster VOR (EMI), 119.2 mc would be selected on the VHF communication system and "Dulles Approach Control" called. Contact having been established the crew would acknowledge further communiques as required. An EAC (Expected Approach Clearance time) would be received as well as any pertinent information on

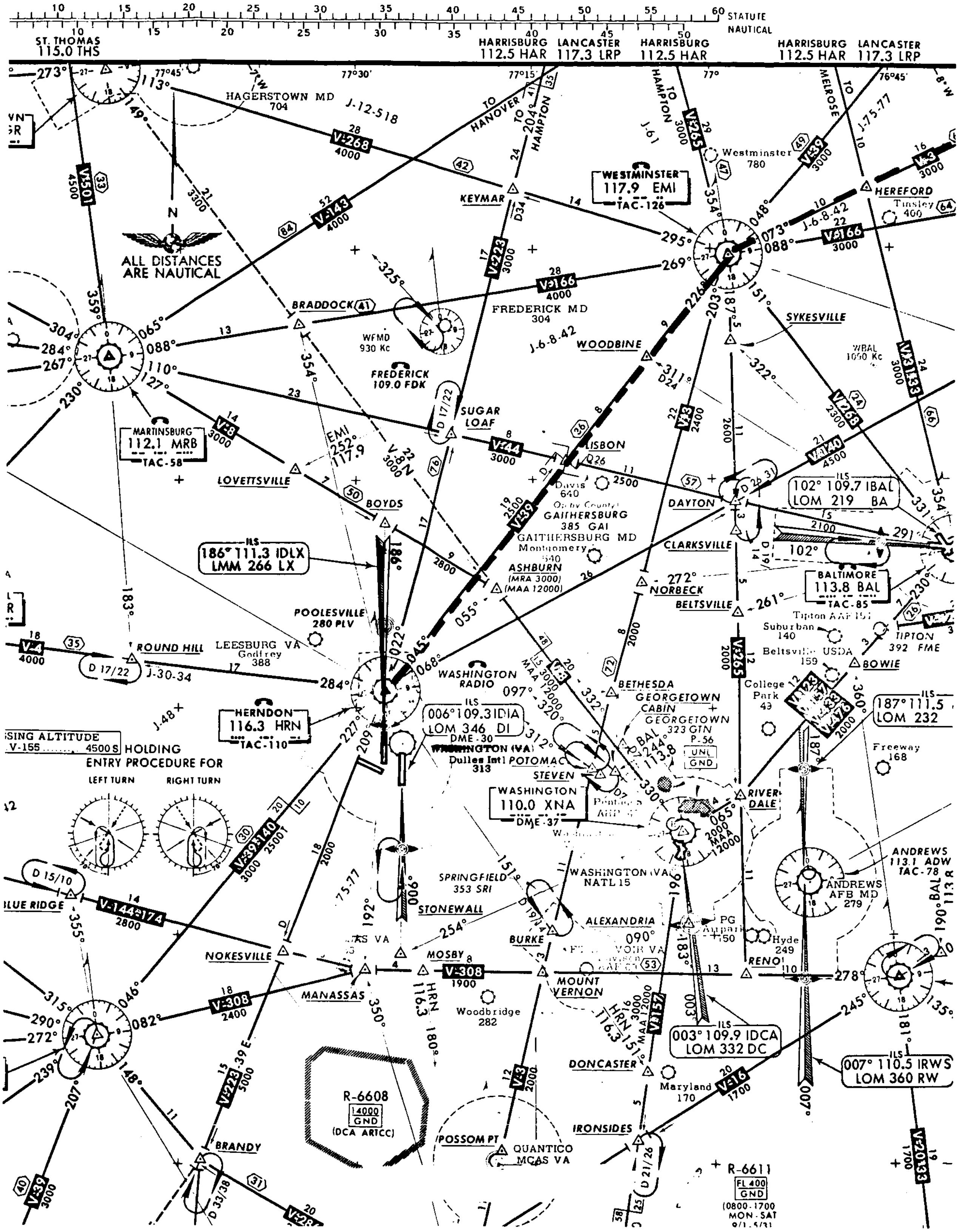


Figure A-4. Initial approach

weather and traffic conditions in the terminal area. The aircraft's beacon transponder provides the ATC facility an automatic identifying and fixing signal as well as altitude coding.

Information received from approach control is used by the crew to determine what effect the traffic density or the approach scheduling will have on their flight. In addition, current weather information in the terminal area plus what weather the crew can observe through the windscreen is assessed to determine the effects on the approach and landing maneuver. It is the crew's responsibility to determine if the weather in the terminal area will permit a safe approach. Finally, the crew would receive advisories from the approach controller as to any other air traffic in the vicinity. But of course, this does not relieve the crew of the responsibility for maintaining traffic vigilance.

So as to fly outbound from Westminster VOR direct to the Herndon VOR, the crew would select 226 degrees on the course selector. The AFCS would intercept the radial and hold it. Enroute the crew would be vectored off the airway so as to intercept the approach path to Dulles ILS (IDLX 111.3 mc).

The crew would continually estimate the aircraft's position relative to the Outer Marker (OM) and evaluate vectors provided them by Dulles approach control, to determine the ILS intercept angle. Using charts and displays like the HSI and ADI, the crew is able to visualize the aircraft's relationship to the final approach path and can obtain information necesary to assess deviation from the assigned course. The HSI provides the crew with a direct indication of the aircraft's position relative to any selected radial (necessary information when flying VOR airways). When the aircraft is being radar vectored, the ATC controller would provide the crew with continual position information.

If while flying airways, a cross-track deviation is presented on the HSI, the crew must assess the implication on the particular flight segment and determine the cause of the deviation. Knowledge of present position is a constant requirement and radial position and DME distance information is immediately available to the crew. Although off-line, the INS system continues to operate and readouts of distance-to-go and lateral deviations are available on the INS control and display panel.

Radar vectoring by approach control will necessitate configuring the autopilot roll axis for MANUAL and having the crew steer the aircraft with the manual controller in response to the course instructions. However, once the crew has entered the ILS approach course (186 degrees) into the course selector, the VOR/LOC system will automatically intercept the localizer course.

Near the beginning of the intial approach phase, the crew selects the desired rate of descent and the cleared level-off altitude and the AFCS will then control the aircraft's descent to this altitude. Later in the approach, prior to glide slope interception, the crew will switch from auto to manual (or control wheel steering) control of pitch.

Even with ATC vectoring the crew will assess the position of the aircraft relative to the localizer and to the outer marker, and will insure that assigned vectors will result in an appropriate localizer intercept angle. If the aircraft intercepts the localizer at too large an angle the automatic system will be unable to track the localizer.

A final assessment made during this phase by the crew covers the entire initial approach of the aircraft. The speed, the vectoring and the altitude of the aircraft is assessed to determine if the aircraft is in proper position for the final approach.

The crew continually cross checks barometric altitude against the clearance altitude given by ATC, and ascertains that the altitude of the aircraft is above the minimum safe altitude for the particular area as shown on approach plates or enroute charts.

The speed of the aircraft will require several changes during this phase segment. The crew will select the desired speed on the A/P-F/D panel and the Autothrottle (A/T) will obtain and maintain that speed.

The autothrottle has a test function which provides the crew with an operations status light as well as a malfunction warning light. The crew is able to monitor the testing operation by noting how well the A/T system maintains the selected airspeed.

With the autothrottle engaged the crew selects a desired airspeed which is displayed both as a selected airspeed and as an index on the airspeed indicator. This type of display provides a direct relationship betwen actual and desired airspeed. If the crew does not utilize this mode of operation, some appropriate speed must be recalled and compared with actual airspeed, and then adjust power controls to maintain desired airspeed.

Using the UHF transceiver the air carrier's operational frequency would be selected to receive a gate assignment, and to provide the dispatcher with an ETA.

If the variable position nose is not in the full down position it is placed in that position to give maximum visibility during landing. The variable sweep wing is checked to see if it's in its landing position (i.e., 30 degrees). The nose position indicator should indicate full down, the crew is also able to visually check the nose position. A wing sweep position indicator provides information on the position of the wing. The landing gear would be lowered, and the crew would select the appropriate aircraft lift/drag devices (flaps/slats) as required by SOP, gross weight, etc. Information on the position of these devices is displayed to the crew via flap/slat position indicators.

A series of warning indicators for the landing gear system are provided. With the landing gear control in the down position a visual indication of gear down and locked is displayed. If the gear is in an unsafe condition a warning light in the landing gear handle as well as a buzzer and blinking light will warn the crew of the malfunction.

As the aircraft approaches the ILS localizer course the crew sets flight controls and thrust level to maintain 3,000 feet. The aircraft would be cleared over Poolesville NDB at 2,300 feet to commence its approach to Dulles.

Under VFR conditions the crew is able to see any terrain features which might endanger the aircraft during its approach. While under IFR conditions the crew must relay upon final approach charts which depict the position of obstacles (see Figure A-5).

Under the assumed weather conditions, the crew will select the LAND mode on the AFCS and the approach and landing will be made automatically. The crew will have to set 186 degrees (the localizer approach course) into the course selector. Aircraft deviation from this course will be shown on the HSI. The approach progress panel annunciator lights glow amber when the localizer capture mode is armed. Once the crew has selected the ILS frequency of 111.3 mc and the desired course of 186 degrees, and the aircraft comes within the appropriate envelope the capture maneuver automatically commences and the annunciator turns green. The crew obtains information on the operation of the AFCS system during localizer acquisition by processing information on the performance of the aircraft. Information on the aircraft's position relative to the localizer and the glide slope is presented on the ADI and the HSI. With this information the crew is able to visualize the aircraft's position and thereby assess the performance of the AFCS.

The "glide slope capture" annunciator changes from amber (armed) to green when the capture maneuver is successfully executed. The crew is provided with information on the aircraft's relationship to the glide slope both on the ADI and on the HSI.

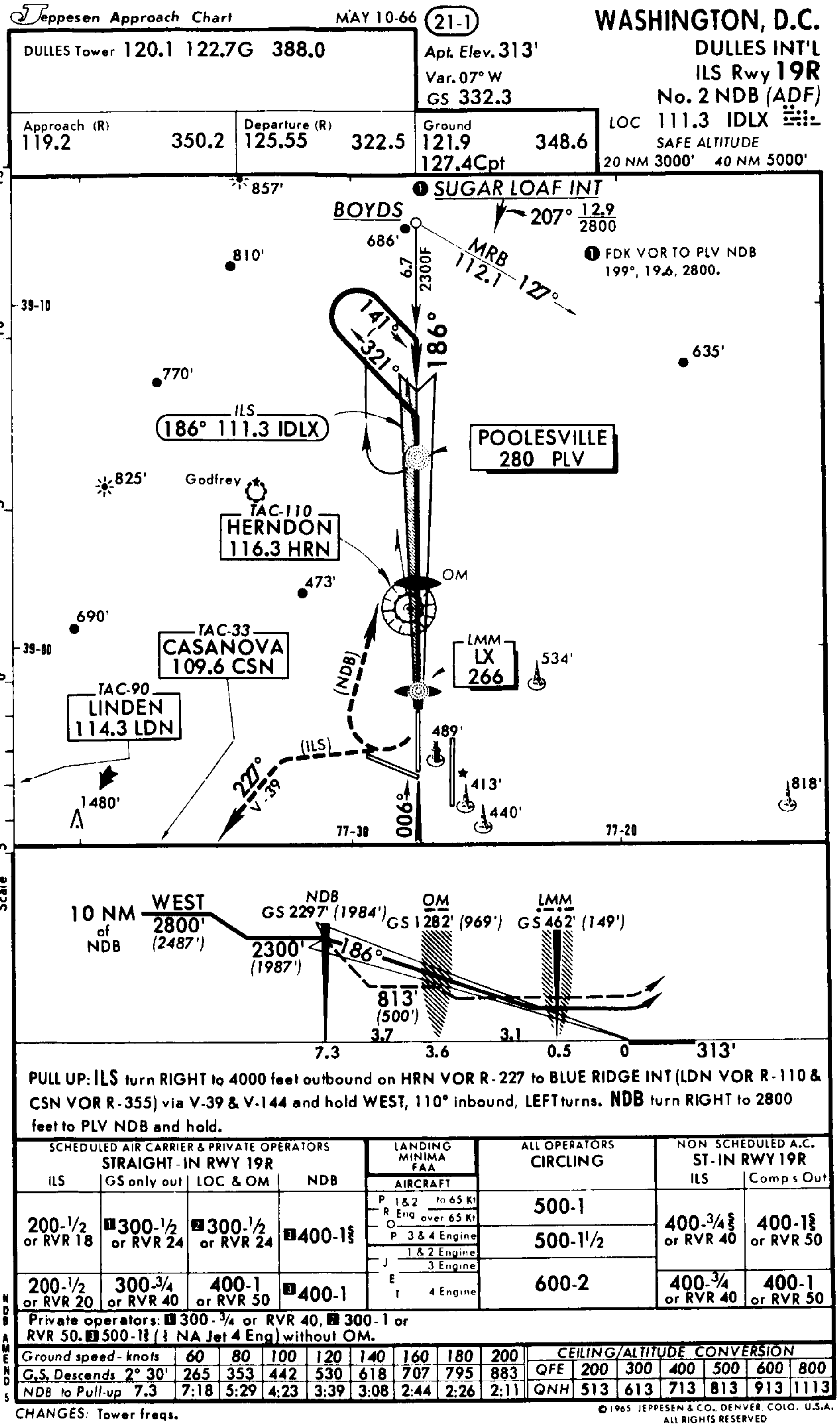


Figure A-5. Approach Plate for Dulles International Airport

The LVLS has a set of internal test functions. Test results are displayed to the crew via an annunciator panel. In addition the crew is able to monitor the overall performance of the aircraft and thereby judge whether performance of the BWLS is within acceptable tolerances. Malfunctioning of any component within the aircraft must be assessed in light of the other conditions affecting the approach. During extremely bad weather conditions a malfunctioning component may require diversion of the flight to an alternate. If however, the malfunction is not deemed critical to the approach, the flight would continue to the planned destination.

On the basis of all the information that has been assimilated by the crew pertaining to flight progress, aircraft performance, operational conditions, and aircraft subsystem operation, the crew must determine if the flight should continue with the final approach. At any time during this initial approach that the flight situation moves outside some acceptable performance envelope the crew may elect to execute a missed approach.

Under normal circumstances, that is, when both IFR and VFR traffic is being landed at Dulles International, approach control would release control of the aircraft and instruct it to contact Dulles tower on frequency 120. 1 mc for final landing clearance. The crew would select this frequency on their VHF communication equipment and call Dulles tower for landing instructions. In those instances when only IFR traffic is landing at Dulles International, the aircraft would probably remain on approach control frequency until the landing has been completed.

Final Approach

With the aircraft turning inbound near the Poolesville NDB at 2, 300 feet and with the localizer acquisition mode functioning properly the final approach phase segment commences.

The crew selects the final approach speed and inserts it in the ATC system, which automatically compensates for wind or weather conditions and will add or decrease power as required. To monitor the A/T performance the crew is provided with an A/T warning light. In addition the crew can monitor the actual speed of the aircraft and compare it to the selected airspeed. Compliance without large variations in the power settings provides a backup check of the autothrottle system's performance.

With the AFCS in the LAND mode and with the aircraft tracking the Dulle ILS, signals from the glide slope transmitter will be received and processed by the AFCS so as to vary the aircraft's rate of descent as a function of the aircraft's selected final approach airspeed. Although presented with an indication of actual rate-of-descent, the crew must resolve whether this value is within an acceptable envelope. Only when this value is viewed in terms of what the aircraft is doing and its location relative to both the localizer and the glide slope can the crew assess whether the rate of descent is appropriate. With the autothrottle engaged and the aircraft maintaining a constant airspeed and rate-of-descent so that the aircraft is tracking the glide slope, the crew has no real concern over the amount of thrust being utilized. If a go-around were indicated the pilot would manually push the throttles forward.

Under IFR conditions approach control would continue to give steering commands until touchdown. At other times the control of the flight would be transferred to local control over the outer marker. The crew would inform the tower of their position and commencement of approach. The tower would provide advisories pertaining to other traffic, advisories on existing weather conditions, and issue the appropriate landing clearance.

The air traffic controller may indicate adverse weather conditions in the vicinity of the airport and the crew would have to make a judgment as to the effect of these conditions on their approach. Some idea of the wind direction and velocity may be derived from the assessment of the aircraft's crab angle.

Throughout the final approach the crew monitors both the ADI and the HSI to determine how well the automatic system maintains the aircraft on the ILS localizer. Aircraft heading is contantly provided and when compared to the ILS approach course provides the crew with any deviation indication. If the aircraft is on the ILS approach course but its heading differs from the ILS approach course then the crew may be alerted to a wind condition. The angular deviation is the amount of decrab the aircraft will need as it transitions from flare to final rollout.

During this phase weather and other factors directly affecting the approach must be constantly assessed. Assessment of turbulence is largely a subjective matter. If turbulence is encountered, the crew must decide what effect it will have on the aircraft's approach. If it is severe enough the crew may elect to abort the approach. The crew must recall information on obstacles in the vicinity of the final approach and assess the aircraft's position relative to these obstacles and determine if either the terrain or the obstacles will prove hazardous to the aircraft on its final approach.

As the aircraft nears the Middle Marker (MM) the crew should continue to monitor LVLS operation. While provided with a set of warning lights which display internal test results the crew will continue to analyze the available information on aircraft performance to evaluate the operating condition of the LVLS. The impact of a malfunction in the LVLS will vary and depend upon associated conditions. With Cateogory II minimums, the crew would be able to disengage the automatic system and manually control the aircraft through touchdown. However, under IFR conditions with extremely low ceilings and very limited visibility, a simple malfunction in the system may be cause enough to abort the approach.

During the final approach the crew is provided with aircraft performance data obtained through communications or visual reference and is considered by the crew in deciding whether to abort the approach. Information processing for this function is continuous throughout the final approach (i.e., as the information is scanned and processed, a continuous question is posed: "should the approach be continued or not?"). The final resolution of the question must be made as the aircraft approaches the decision altitude (for Category II). Under Cateogry II conditions the automatic system would be disengaged if the pilot flying the aircraft has made visual contact with the approach lights, sufficient to manually continue the approach, by the time the aircraft has reached the decision height.

Thus, throughout the approach the crew is called upon to assess and evaluate both the performance of the aircraft and its various subsystems. When a malfunction or a non-routine operation occurs that is not covered by some standard operating procedure, the crew is required to call upon past experience and knowledge in order to decide upon some course of action which will maintain the safety and integrity of the aircraft. The exact position of the aircraft, the weather conditions, and the seriousness of the malfunction are all factors which may add to the criticality of that function.

Landing

As the aircraft crosses the threshold and is at a height of about 70 feet, the flare computer automatically flares the aircraft upon receiving a signal from the radio altimeter. The crew monitors the operation of this automatic function. During VFR conditions with the crew flying the aircraft they visually judge when the aircraft is at the appropriate height to commence the flare maneuver. The object of this maneuver is to reduce the rate-of-sink to approximately two to three feet per second or about 200 feet per minute. The flare computer in the automatic landing system status is displayed by an annunciator light which is amber when armed and turns green when the function is initiated. The crew should be aware of the programmed flare altitude to be able to assess the operation of this function. As the crew are in the control loop they will be able to immediately take control if a malfunction were to occur. The crew is provided with a display of the command pitch on the ADI and has available to them a direct readout of the rate of descent. Based on past experience the crew can determine if the pitch attitude of the aircraft is changing sufficiently and if the rate of descent is decreasing within that which is optimum for touchdown.

During the flare and subsequent decrab and touchdown.runway lighting provides the crew with some reference for runway alignment. As the aircraft starts its flare the crew may be presented with a distorted view of the aircraft's relationship to the runway because of a large crab angle. A display of the aircraft's position relative to the ILS localizer and an indication of the aircraft's crab during the flare maneuver and the subsequent decrab, is provided to allow the crew to assess the position of the aircraft relative to the runway centerline. This information should correspond to that presented on the instruments.

Because of the size of the SST, under all conditions the crew may find it difficult to determine the attitude of the aircraft by using only visual means. If the aircraft has too great a nose up attitude at touchdown it is conceivable that the aft portion of the aircraft could be damaged upon landing. For this reason the crew is provided an indication of the rate-of-descent. Comparing these with what is considered optimum allows the crew to determine the effectiveness of the particular maneuver.

Once the aircraft has landed the autothrottle system would reduce power to idle. The crew would actuate and control the reverse thrust mechanism as required so as to decelerate the aircraft within the runway remaining. To the extent that the crew can see the runway lights or the runway centerline or any other visual references they should be able to evaluate the aircraft's performance in maintaining directional control during rollout. Although there is no direct indication of the deceleration of the aircraft to normal taxi speed the crew is provided with airspeed data. Using this and visual reference of the aircraft's position on the runway relative to the end of the runway the crew is able to judge if the rate of deceleration is sufficient. Although provided with a light which indicates the operation of the thrust reverse system the only indication of the total operation of this system and any of the drag devices will come through the performance of the aircraft. A deceleration of the aircraft in response to a variation of the thrust reversal system and/or drag devices would indicate that the systems were operating corectly. Little can be known with certainty about how the wheel brakes will perform prior to their actual use. Then, the only scale of performance is one based on response (i.e., how the aircraft reacts when the wheel brakes are applied).

Once the aircraft has touched down, the crew still has the responsibility to determine if the aircraft can be stopped within the runway remaining. If conditions of the runway are severe (e.g., snow, rain, on the runway) or system failure is experienced such as the brakes or thrust reverser the crew may have to select "go-around" (i.e., try the approach again).

REFERENCES

1. Ridenour, A. R.: Rush Hour -- Standard Operating Procedures. AIAA Paper No. 67-398, AIAA Commercial Aircraft Design and Operations Meeting. Los Angeles, June 1967.

2. Gartner, W.; Ereneta, W.; and Donohue, V.: A Full Mission Simulation Scenario in Support of SST Crew Factors Research. NASA, 1967.

3. Osder, S. S.: Avionics Requirements for All Weather Landing of Advanced SST's. NASA CR-73092, 1967.

4. Boeing Model 2707, Supersonic Transport Development Program, Phase III Proposal, V1-B2707-1, FA-SS-66-5, 1966.

5. Beck, R. H: The Revival of the "One Man Band", ALPA All Weather Flying Committee, 1967.